APPLYING THE CRITICAL PATH METHOD TO CONSTRUCTION PROJECTS.

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TO

CONSTRUCTION PROJECTS

A MASTER' THESIS

by

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PREFACE

"Within two weeks after written or verbal notice of award of contract, the contractor shall submit to the Telephone Company a critical path method analysis of the job schedule..."

American Tel. & Tel. Spec. No.
SA - 1562 of December 10, 1963

From the foregoing statement it is evident that CPM (Critical Path Method) has achieved significant importance in the construction industry. Specifications such as this are appearing more frequently in construction contracts, especially in the aerospace field. This trend, which is constantly being abetted by a preponderance of favorable testimonials for CPM, leads this writer to believe that in the very near future almost all contractors will be required to have a CPM capability if they wish to survive in the highly competitive construction industry.

The intent of this thesis is to assist engineers and contractors in understanding, implementing and working with the Critical Path Method.

The writer wishes to express his appreciation to the Civil Engineering Corps, United States Navy, for the opportunity to make this study and to Professors W.E. Blessey, R.N. Bruce, F.J. Dalia and J.L. Niklaus of the Civil Engineering Department of Tulane University for their advice and encouragement.

Appreciation is also extended to Mr. Howard Perrilliat, Mr. Claiborne Perrilliat, and Mr. August J. Barbier Jr. of the Perrilliat-Rickey Construction Co., Inc. who gave generously of their time in advising the writer in regard to construction methods and practices and contract administration.

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INTRODUCTION

It is important that every consulting engineer and contractor comprehend the value and appreciate the significance of the Critical Path Method because this is probably the most effective construction management technique ever devised; and its initial and overwhelming success has generated a trend toward mandatory use on many types of construction contracts.

Since 1958, when CPM began to achieve prominence, hundreds of authoritative papers, pamphlets, articles and dissertations have been written on the subject. Unfortunately, most of this literature falls into one of the following categories:

1. A testimonial which lauds the success of CPM on a particular project.
2. A rigorous explanation of some unique application or modification of the system.
3. Arguments for or against a certain type of CPM technique.

While all this information is valuable it does not fill the engineer's and contractor's need for practical information that can be put to immediate use.

The purpose of this thesis is to furnish a guide devoted to providing the basic information necessary for an engineer of contractor to get started in CPM with a minimum amount of confusion and wasted effort.

It is believed that this objective can best be accomplished by providing:

- no rigorous theoretical explanations or calculations;
- an introduction to the network analysis techniques;
- instruction in the fundamentals of CPM;
- a discussion of cost control with CPM;
- recommendations for implementing and administering CPM.

This then will be the format for this thesis.

THE NETWORK ANALYSIS TECHNIQUES

Network Analysis Defined

Network Analysis is a collective term used to describe the entire family of management planning and control techniques such as: CPM, PERT, TRACE, PEP, LESS, etc.

Network Analysis (also called Network Theory) is a management technique which can be used in the planning and controlling of various types of projects. It can be applied to any project for which there exists a specific goal. The range of possible applications extends from organizing a church supper to controlling the most complex space project.

The objective of Network Analysis is to achieve the most effective use of manpower, time, materials and money.

Of all the Network Analysis techniques, CPM and PERT are the most popular. The other acronyms mentioned above which are not so widely known are defined as follows:

PEP (Program Evaluation Procedure)

TRACE (Task Reporting and Current Evaluation)

LESS (Least Cost Estimating and Scheduling)

A more extensive listing of these techniques is contained in the appendix.

The common thread that binds all of these techniques together is the use of a network diagram made up of activity arrows each of which represents the accomplishment of some particular item of work that is part of the over all project.

For a given project, Network Analysis basically consists of the following steps:

1. Drawing a network (arrow) diagram which acts as a graphic representation of the activities necessary to accomplish the project.
2. Estimating the amount of time required to accomplish each activity in the network.
3. Determining the longest path through the network called the critical path.
4. Adjusting the network in order to determine the sequence for performing the activities which will result in the least amount of time and expense.
5. Using the network to control the project.

The Mechanics of Network Analysis

The inner workings and hidden mechanisms of Network Analysis can be explained by considering a simple network diagram for a hypothetical project, such as shown in figure 1.

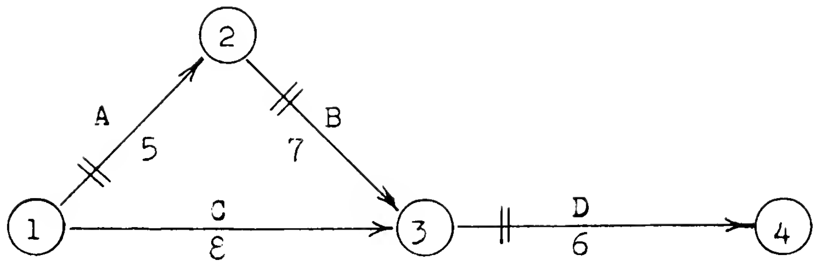

Figure 1. Simple Network

This project is composed of activities A, B, C, and D. Each activity begins with an event and ends with an event. The events are labelled 1, 2, 3, and 4. Activity A begins with event No. 1 and ends with event No. 2. Activity C also begins with event No. 1 but ends with event No. 3 and so on for activities B and D.

Each activity has been assigned an estimated time for completion which is called the duration and this case it is assumed that the time units are days. The duration of activity A is five days, activity B is seven days, etc.

The longest time path through this network is via events 1-2-3-4 or it consists of activities A, B, and D. This is called the critical path and it is usually distinguished by hatch marks or a suitable color code.

Comparing the two paths available to reach event No. 4 it can be seen that path 1-3-4 is 14 days long and path

1-2-3-4 is 18 days in duration. Path 1-3-4 therefore contains a float of 4 days which means a 4 day delay can be tolerated along path 1-3-4 before the project completion time will be affected.

The main ingredients of Network Analysis are:

a. activities

b. events

c. activity durations

d. critical path

e. float

In constructing the network diagram the following questions must be asked about each activity:

1. What other activities must be completed before this activity can start?

2. What other activities can be accomplished concurrently with this activity?

3. What activities immediately follow the completion of this activity? [1]

This is called the network logic. To sample the validity of this logic look again at figure 1. For this network it

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[1] Stilian, G. and Others, PERT: A New Management Planning and Control Technique, (New York: Amer. Management Asso., 1962), p. 148.

can be seen that activities A and C start at the same time and run concurrently; activity B cannot start until activity A is completed; and, activities B and C must both be completed before activity D can begin.

Another important feature that should be mentioned is the fact that the arrows of the network diagram are not vectors, i.e., their duration is not a function of their length or direction. They are used only to indicate the interrelationships and interdependencies of the activities.

The principles which form the nucleus for all the Network Analysis techniques have now been exposed. All of the techniques are derived to a greater or lesser degree from the basic network theory just discussed. The techniques are distinguished from each other by modifications of the basic network theory to meet the specific needs of an industry or particular project. As it happens, CPM and PERT are the most widely used techniques because they are the most versatile, i.e., between the two almost every type of project can be accomodated.

The Effectiveness of Network Analysis

Everyone who has worked with Network Analysis will agree that the greatest benefit derived from its use is that it forces people to think logically and constructively about their projects. It is actually a thought process expressed graphically by an

arrow diagram indicating the duration, the sequence, and, if desired, the cost of every task necessary to complete a given job.

Its value is further enhanced by the fact that it enables the user to acquire an unusually good grasp of an entire project including potential trouble spots in a relatively short period of time.

Of course, this is really not so exceptional when you consider that (i) the graphic presentation provided by a network diagram is much more comprehensible than a narrative description of the same material, and (ii) in developing a network diagram one has to contemplate the relationships and interdependencies of the project activities. Even in the case where someone is responsible for only one phase of a project, Network Analysis given him an acute awareness as to how his performance will affect the other phases of the project and conversely, how the other phases will affect his work.

The flow of accurate and timely information from the office to the field and back again is vital to the existence of any company. Network Analysis provides an excellent medium for the transmission of this information since it will clearly indicate progress and pin-point trouble spots. The network may contain as much or as little detail as may be considered consistent with the size or the importance of the project.

On first exposure to Network Analysis (usually CPM) some contractors have claimed that it is no better than the bar

charts they've been using successfully for years. In some cases this is true and it is admittedly difficult to see any advantage on a small project of 100 activities or less because the relationships of the various activities are rather obvious <u>if</u> a person is well experienced in construction methods and practices; however, when a project approaches several hundred or a thousand activities it is virtually impossible to tell at a glance from a bar chart how a delay in one activity will affect the other dependent activities and to what extent.

With Network Analysis, regardless of the size of the project, the results of a delay in any activity can be easily determined in terms of both time and cost.

Network Analysis is versatile. It has been used successfully to plan and control the following types of work:

a. Research and development programs.

b. Construction projects.

c. Production of goods and materials.

d. Introduction of new systems and procedures.

e. Installation of new equipment.

f. Maintenance work.

g. Company reorganization.

h. Design projects.

In general it can be said that Network Analysis can

always be used to good advantage on new, untried, and infrequently repeated operations. This is one reason for the popularity of CPM in the construction industry. CPM is attractive in this case because every construction job seems to have its own idiosyncrasies and unusual risks regardless of similar jobs accomplished in the past.

A rather obvious advantage of Network Analysis and another reason for its growing popularity is attributed to the fact that it is computer oriented. Once a network diagram has been developed for a project and the activity times and costs have been assigned, a computer can easily perform the tasks of determining the critical path, developing a time-cost analysis and controlling the project through dynamic reporting and up-dating. This of course is practically a necessity when a project exceeds several hundred activities.

Network Analysis is the ideal solution to the classic problem of management by exception. In using Network Analysis the manager devotes most of his time and energy to the activities that lie on the critical path realizing that any of these items will immediately effect the completion of the project. The other activities having varying amounts of float can be attended to in relation to the amount of float or the weighted degree of importance which is assigned to them. This is a boon to the busy executive who must have timely information and know everything of significance about

many different projects. Network Analysis enables him to make the most efficient use of his limited and valuable time.

Network Analysis is also valuable when a project begins to fall behind schedule and a "crash program" seems desirable to get the project back on schedule. In this case Network Analysis will indicate (i) if a "crash program" is really essential, and (ii) if it is, which activities should receive the most attention. When a crisis develops, the usual tendency of a project manager is to put everything on an overtime basis to catch up. In most cases Network Analysis would show this to be a wasteful procedure and would point out the areas in which the most effort should be concentrated in order to get the project back on schedule in the least time and with the least expense.

In summary it can be said that Network Analysis promotes constructive thinking, aids planning, reports progress, indicates trouble spots and usually results in a substantial savings of time and money.

Origins of CPM and PERT

PERT achieved prominence in the field of management planning and control methods when the nuclear powered submarine the USS George Washington joined the fleet on 15 November 1960. [2]

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[2] Department of the Navy, Polaris Management, Fleet Ballistic Missile Program, A report by Special Projects Office, Department of the Navy, (Washington, D.C., February 1961), p.2.

The event was significant because on this occasion the Polaris Missle became operational almost two years sooner than anticipated. The pace at which the Polaris Missle was developed and produced was unprecedented in the field of weapons systems development.

The credit for this achievement was shared by a team comprized of members from the Navy Special Projects Office, The Lockheed Missle System Division and the management consulting firm of Booze, Allen, and Hamilton. This team was especially well equipped to deal with the problem at hand because of Allen, Booze, and Hamilton's experience in operations research. They started to work in January 1958 and by mid 1958 they had developed a network analysis technique called PERT which turned out to be the main factor of the Polaris' success story.

Although the development of PERT was by no means the beginning of network theory it was a milestone in the history of management planning and control techniques because it greatly stimulated interest in them.

The development of CPM preceded PERT. In 1956 the E.I. duPont deNemours and Co. initiated a study in conjunction with the Univac Applications Research Center of Remington Rand to devise a system for planning, scheduling and controlling complex engineering projects. By 1958 CPM had been developed,

tested and proven successful. In 1959 Dr. John Mauchly who headed up the CPM group at Univac formed Mauchly Associates with the objective of promoting CPM as a solution for industrial management problems. Since then CPM has gained wide acceptance and has been enormously successful in the construction industry.

Today there are several firms that specialize in CPM and the number of these firms will undoubtably grow as the demand for knowledge of CPM increases. A partial list of these firms is contained in the appendix.

Engineering News Record, Construction Methods, Building Construction and most of the other trade journals frequently contain articles describing applications of CPM. The present list of applications appears almost as overwhelming as the success reported, and this writer has not found evidence of any application of CPM that was unsuccessful, if properly applied. Almost invariably from the cases studied, contractors have reported increased profits and earlier project completion through the use of CPM.

As further evidence of its acceptance, it should be mentioned that CPM has been adopted and considered mandatory on certain types of construction contracts by The Navy Bureau of Yards and Docks, The Army Corps of Engineers, The Boeing Company and American Telephone and Telegraph Company, just to cite a few examples.

A Comparison of CPM and PERT

The frequently used term "CPM/PERT" leads one to believe that there is no difference between CPM and PERT. It also gives the impression that CPM and PERT are simply two different trade names for the same technique. Since they are both Network Analysis techniques they have many similarities but they provide different information because they were designed to meet different requirements. The use of "CPM/PERT" should therefore be discouraged.

CPM and PERT are similar in the following ways:

1. They employ the same logic in the development of the network diagrams.
2. Both use practically the same terminology with minor exceptions.
3. Both have proven to be extremely effective when properly used.
4. Within their basic concepts; i.e., scheduling or time, one can be used practically as well as the other for a given project.

The biggest distinction between CPM and PERT is that PERT is event oriented and CPM is activity oriented. This simply means that CPM was designed as a tool for the planning, scheduling and control of construction work where the emphasis

is placed on the activities (operations) that make up a particular project, while in PERT the attention is focused on the planning and evaluation of the events that comprize a large scale research and development project.

CPM can be considered a more precise technique because it deals with the fairly well established work measurement units and costs of the construction industry. For example, every contractor has a reasonably good idea of how many bricks, on the average, each of his bricklayers can lay per day. He also knows the cost of labor and materials for any item of work and he can divide every phase of his work into time and manpower required for accomplishment including the cost for each phase. Since this much detailed information can be developed it is easy to see why the emphasis in CPM is on the activities.

PERT presents almost the opposite situation because research and development type programs typically deal with intangibles, lack of previous experience upon which estimates can be based, and frequent program changes. For these reasons the PERT system is designed to answer the question: Is the schedule feasible and what are the chances of meeting it? It is obvious then that PERT is based on activities being started or completed by certain target dates and thus the occurrence of the events or "milestones" as they are sometimes called assume greater im-

portance than the activities.

PERT copes with the problem of uncertainty by using statistical methods. In the determination of the activity durations PERT uses 3 time estimates to arrive at what is called the expected time. This is a statistical mean computed as follows:

$$te = \frac{a + 4m + b}{6}$$

where:

a = the optimistic time estimate

b = the pessimistic time estimate

m = the most likely time estimate

te = expected time [3]

The optimistic time represents the time required to complete the activity assuming things go unusually well. The pessimistic time is the duration of the activity assuming that a number of problems occur (but not an unreasonable number). The most likely time is the one which would usually be given if only one estimate could be used. Note that the most likely time receives 4 times the weight of the other two time estimates.

In CPM a single estimate is used for the activity time and it corresponds to the most likely time estimate used in

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[3] Department of the Navy, PERT Summary Report, Phase I, A report by Special Projects Office, Department of the Navy, (Washington, D.C., July 1958), p.7.

the PERT system.

To further compare these two major techniques assume a hypothetical project for laying a quantity of sewer pipe and develop both a CPM and a PERT network for this project. Figure 2 shows the project as it would appear if CPM were used and figure 3 shows the same project analyzed by PERT.

Looking at these two networks it is apparent that:

1. The PERT activities are composed of 3 time estimates while the CPM activities use only one.

2. The CPM activities indicate that a certain action is taking place, while the PERT events indicate that action has either been completed or is just starting.

3. The PERT network would be better to use if target dates for completion of activities were of major concern, whereas CPM would be more suitable if we wished to work with costs and manpower allocations.

4. The CPM network could be solved manually without difficulty whereas the PERT network lends itself to computer solution because of the statistical calculations.

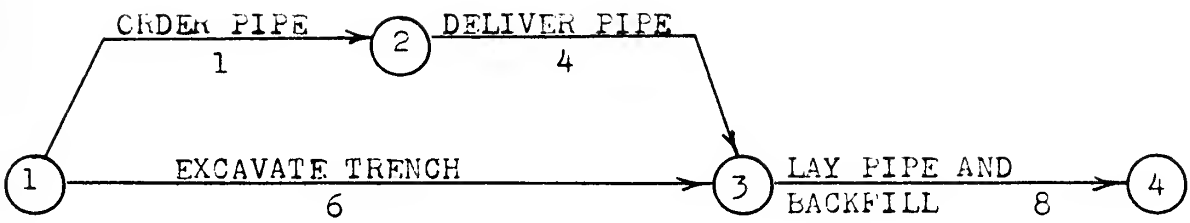

Figure 2. CPM Network

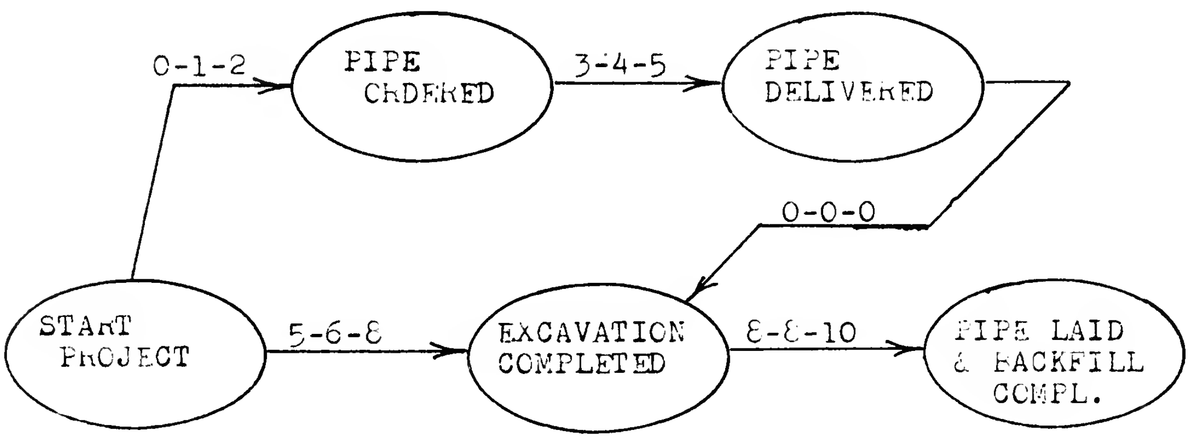

Figure 3. PERT Network

In summary it can be said that PERT is used to best advantage on research and development type projects, while CPM is the most effective technique for construction work. Further, where the best possible cost estimates must be obtained and reliable activity time estimates are available, CPM is the logical choice.

A recently developed PERT program called PERT/COST [4] attempts to overcome PERT's shortcomings in the control of activity costs but for construction work it still leaves something to be desired and greater refinement is necessary if it is to compete with CPM in this category.

In favor of both of these systems it can be said that between them almost any type of program or project can be accomodated, but it should be remembered the results of both will only be as good as the input data.

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[4] Anzelon, G.J., "CPM or PERT - What's the Difference?", A special reprint from The Constructor by Reuben N. Donnelley, Corp., (New York, not dated), p. 41.

THE FUNDAMENTALS OF CPM

In this section a deliberate step by step explanation of the workings of CPM will be undertaken. In order to make this explanation as meaningful as possible a hypothetical project will be used to demonstrate the drawing of the Network Diagram and the determination of the Critical Path. This will consist entirely of manual calculations to insure a firm grasp of the fundamentals. Computer solutions will be discussed later.

The format for accomplishing this consists of the following major phases:

I. Drawing the Network Diagram

II. Estimating Activity Times

III. Determining the Critical Path

IV. Adjusting the Network

To further augment this broad four phase breakdown the first three phases will also include five basic procedural steps. The selected project will consist of a reinforced concrete Radiation Block House which is to be used by a research agency for experiments involving radioactive materials.

I. Drawing the Network Diagram

Before drawing the network diagram for our project a brief explanation of CPM diagram terminology, symbols and network logic is in order. First, the definition of the basic ingredients of the CPM network.

CPM Diagram Terminology and Symbols

ACTIVITY:

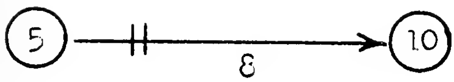
A specific task to be performed which requires the expenditure of manpower or material resources. It represents a definite amount of effort applied over a period of time and it is bounded on both ends by events. It is represented by an arrow.

EVENT:

A point in time which indicates that an activity has just started or has just been completed. The event itself does not represent a quantity of work. It is indicated by a circle which contains an identifying number.

ACTIVITY DURATION:

The best estimate of the time required to complete the activity. Time units are usually days or weeks and fractions thereof. The duration



appears beneath the activity arrow. In the illustration it is 8 days.

CRITICAL PATH:

The longest path through the network. It is the sequence of activities and events which require the most time for completion. It is possible to have two or more critical paths; however, in this case an evaluation of the network should be made in order to improve the schedule. There are two important aspects to the critical path. First, if the overall project time is to be shortened, one or more of the activities along the entire path must be shortened. Second, if the actual time of an activity on the critical path varies, the time required for project completion will also vary on a one to one basis. An activity on the critical path is usually disting-

uished by hatch marks, heavy lines, or colored lines.

FLOAT:

Since the critical path is the longest path through the network, all of the other paths are naturally shorter. This difference in time between the critical path and any of the other paths is called float. The amount of float indicates the number of time units (usually days) that a project may be delayed or extended without affecting the scheduled completion of the project. The maximum amount of time available for the performance of an activity is called Total Float and this is the float which is of primary concern. There are other types of float namely: Free Float, Independent Float, and Interfering Float, but they are of marginal usefulness and will not be discussed. The

amount of float for each path is not normally indicated on the network.

DUMMY:

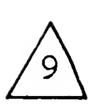
A nameless activity with zero (0) duration. It is used only to preserve the continuity and maintain the logic of the network.

EARLIEST EVENT TIME (EET):

$\boxed{8}$

Indicates the earliest time that a particular event may be reached, all paths considered. The symbol is placed on the network diagram directly above the event to which it pertains. The symbol shown indicates 8 days are required to reach the event in question.[5]

LATEST EVENT TIME (LET):



Indicates the latest time that an event may be reached. EET and LET provide the basis for the manual calculation of the Critical

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[5] Waldron, A.J., Fundamentals of Project Planning and Control, (Haddonfield, New Jersey, August 1963), pp. 27-31.

Path. The LET symbol is also placed on the network diagram, but just above the EET symbol and both are above their corresponding event. The symbol shown indicates that the event must be reached in no later than 9 days.[6]

It is quite possible that the use of EET and LET is rather vague at this point, but this should not be of great concern since their value and their use will become apparent once work begins on the project network.

The next item on the agenda is a discussion of network logic. First, some rules of the road for drawing the network then a few examples.

Network Rules

1. Each activity is represented by one arrow.
2. The arrows are not vectors. Their length and direction do not indicate duration. Their length is a matter of convenience in order to present the network clearly and maintain the logic.
3. All activity arrows begin and end at events.

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[6] Ibid.

4. The head of the arrow indicates the completion of an activity and the tail indicates the beginning.

5. Activity arrows that originate at an event that acts as a junction for several arrows entering the event cannot begin until <u>all</u> of the activities that terminate at the event have been completed.

6. A dummy arrow is used to show the precedence of one activity over another when these activities are not directly related by an activity arrow.

7. No two events may have the same number and each event must have a higher number than the one that precedes it. [7]

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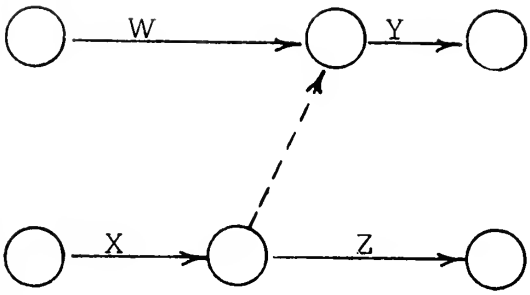
[7] <u>GE - 225 Application, Critical Path Method Program</u>, A Brochure prepared by the General Electric Co. Computer Department (Phoenix, Arizona, 1962), p. 4.



Activity Y cannot start until both activities W and X have been completed. Activity Z may start independently of activities W and Y but not until X has been completed. The dummy arrow is sometimes called a restraint since X imposes an additional restraint on the commencement of Y.[7]

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[7] Daly, J.E., PERT Network Practices, A pamphlet prepared by the Civil Engineer Corps Officers School, U.S. Navy, (Port Hueneme, California, 1963), p.22.

Network Logic Problems

To insure an understanding of network diagraming the following problems will be helpful. The answers may be found in the appendix.

1. Draw a network diagram which indicates activities A and B are to be performed concurrently but that both A and B must be completed before activity C can start.
2. Draw a network diagram showing that activities A and B start concurrently but that activity C cannot start until A is finished while D cannot start until B is finished. Also assume that B imposes no restraint on the start of C and A does not restrain the start of D.
3. Draw the network diagram if activities A and B start at the same time and run concurrently but C cannot start until both A and B are completed while D may start as soon as B is completed.
4. Draw a network diagram for the construction of a concrete footing given the following activities.

    Excavate

    Deliver Reinforcing Steel (Rebar)

    Deliver Concrete

    Set Formwork

    Set Rebar

Pour and Cure Concrete

Strip Forms

Development of the Project Network

Having discussed the network diagraming criteria and worked a few illustrative examples, development of the project network for the Radiation Block House may begin.

In a nutshell, the process of developing a CPM network diagram is a graphical extension of a good construction estimator's thought processes which occur as he "takes off the job"; i.e., it is built from the ground up in natural sequence.

The necessary structural details are provided by Plate No. 1 and the following comments are offered in lieu of formal specifications:

1. The contractor will perform all work with his own forces.
2. In general, the structure will be austere-no ginger-bread, no finished floors and no painting other than exposed metal and doors.
3. No plumbing is involved.
4. The only mechanical work is the ventilation system.
5. The electrical work consists of lighting and power supply for equipment.

6. The roofing to be 3-ply built-up roof with slag cover.

7. The lead door is in two sections for ease of installation.

8. All equipment will be installed by the owner.

Step No. 1 - List the Activities

After analyzing Plate No. 1 a general listing of all the operations (activities) that must be performed in order to build the structure is made. This list of activities need not be in exact sequence (this would be getting ahead of the game since the CPM network will determine this). The complete activity list for the Radiation Block House is as follows:

ACTIVITY LIST-RADIATION BLOCK HOUSE

Network Identification	Description of Activity
1. SITEWORK	1. Site clearing and drainage
2. EARTHWORK	2. Excavation and grading
3. FLOOR SLAB	3. Set forms, place rebar and electric conduit, pour floor slab including test pad, cure slab and strip forms
4. DEL STEEL	4. Place order and arrange for delivery of reinforcing steel (rebar)

5. PREP SHOP DWGS	5. Prepare and submit shop drawings to the Architect for the radiation port window, doors, and their frames.
6. APPR SHOP DWGS	6. Obtain Architect's approval for the above shop drawings.
7. DEL DOORS	7. Upon receipt of the Architect's approval order window, doors, and frames and arrange for their delivery.
8. INSTALL DOORS	8. Install the window and doors.
9. WALLS	9. Set forms, place rebar and electrical conduit, pour walls including test pad walls, cure all walls and strip forms.
10. ROOF	10. Set forms, place rebar and electrical conduit, set exhaust vent sleeve, pour concrete roof slab, cure roof and strip forms.
11. ROOFING	11. Install 3-ply built up roof with slag cover.
12. MECHANICAL	12. Install ventilation system.
13. ELECTRICAL	13. Install service leads, service

	entrance, power supply circuits, lighting circuits, fixtures, and circuit breakers.
14. PAINT	14. Paint all miscellaneous iron work, metal doors and window frames.
15. CLEAN-UP	15. Grade site and clean up debris.

Comments on Step No. 1

The purpose of the Network Identification column in the activity list is to provide the briefest possible label for each activity. This will prevent the network diagram from becoming too cluttered. In actual practice it is not necessary to describe the activities in so much detail as long as everyone concerned understands the full meaning of the abbreviated descriptions.

An effort has also been made to keep the number of activities to a minimum in order to make this presentation as clear as possible yet typically representative. The programmer may include more or less detail in accordance with his requirements. For instance, it would be easy to break down the FLOOR SLAB activity into the following activities:

Floor Slab Forms

Pour Floor Slab

Cure Floor Slab

Strip Floor Slab Forms

The degree to which the activities are broken down depends on the contractor's construction methods, whether or not there are subcontractors, and in general how closely the work is to be controlled. There is obviously a point at which it becomes foolish to provide a further breakdown of activities, but each firm will have to determine this individually through experience.

The shop drawing and reinforcing steel activities appear on this relatively simple project in order to emphasize their importance.

The handling of the shop drawing activities should be especially noted. Care has been taken here to ensure that the preparation and submittal of the shop drawings and the approval of the shop drawings are separate activities since the latter is the responsibility of the architect and the former is the responsibility of the contractor. This writer found on one occasion a CPM Network (developed by an owner and included in the contract bidding documents) in which the contractor was required to comply with a network schedule, yet one of the activities for which the contractor was to be responsible was partially the architect's responsibility. The activity in this case was listed as "Approval of Shop Drawings and Delivery of Materials".

<u>Step No. 2-Draw the Network</u>

Now that the activities have been listed the next step is to draw the network diagram and the first question to be asked is:

"What activity (or activities) must be accomplished first?" Looking the list over it is apparent that SITEWORK, DEL STEEL and PREP SHOP DWGS can all start immediately and concurrently. The network then will start as shown below:

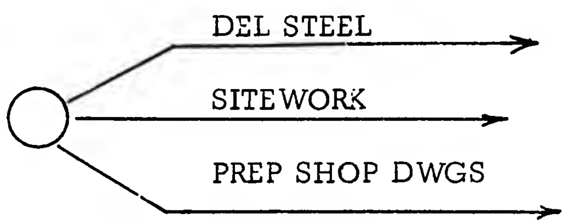

Figure 4. Partial CPM Network I

Next, the activities that immediately follow each of the above activities must be determined.

It is reasonable to assume that DEL STEEL must be completed before any concrete can be placed and that PREP SHOP DWGS must be accomplished before the drawings can be approved by the architect or engineer. Both of these items will come into play shortly, but they certainly don't begin immediately after SITEWORK; so they can be put aside for the moment. Considering the remaining activities EARTHWORK becomes the logical choice to succeed SITEWORK. After EARTHWORK would come FLOOR SLAB, then WALLS, and then ROOF. The network has therefore progressed as shown in figure 5. Note that the DEL STEEL activity arrow has terminated at the first concrete pour which is FLOOR SLAB.

Figure 5. Partial CPM Network II

What else can be added to our network now? After ROOF would come ROOFING and after that the project should be far enough along to begin the PAINT work. APPR SHOP DWGS and DEL DOORS can be added to PREP SHOP DWGS and DEL DOORS must be terminated at the beginning of WALLS since the door frames must be set in the wall forms before the concrete is placed. The ELECTRICAL work can start on the outside as soon as the walls are finished then can move inside as soon as the roof form work shores are removed and it should be finished before the PAINT work begins. The MECHANICAL work and the installations of the doors can begin as soon as the ROOF is finished. Add the CLEAN-UP work after the PAINT job and the complete network diagram is obtained as shown in figure 6.

Comments on Step No. 2

The events in figure 6 have been numbered so that each activity may now be identified. The first activity identification number is called the "i" number and the last is called the "j" number. For instance, FLOOR SLAB is identified as the activity whose "i-j" number is 8-12.

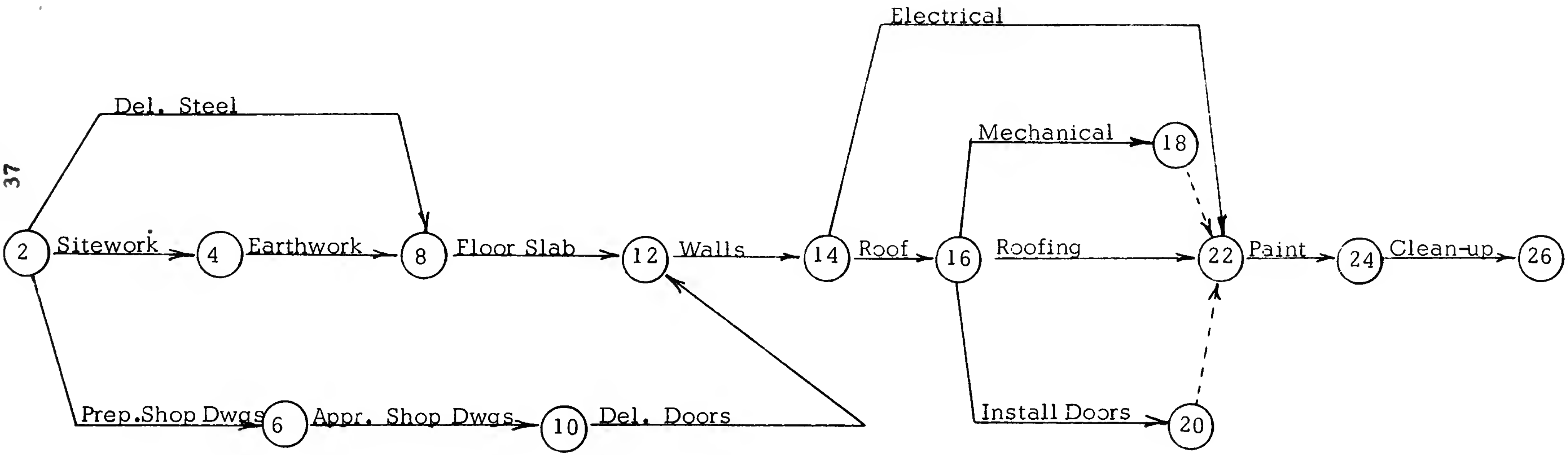

Figure 6. Complete Network Diagram

This method of marking will be a definite advantage when it comes to computer solutions.

The events have been numbered by 2's for convenience. They could have just as easily been numbered in the sequential mode (1, 2, 3, 4, 5, etc.) but this would require renumbering the whole network every time we wished to modify the network by adding another activity.

The "i" number must always be of lower value than the "j" number for the activity being identified. A good illustration is the case of two activities that have one event number in common such as WALLS and ROOF. They are properly identified as:

i	j	activity
12	14	WALLS
14	16	ROOF

But what about the use of the dummy activities 18-22 and 20-22? The reason for this is not so much to impose restraint as to provide proper identification. For example, if the dummies were not used the MECHANICAL, ROOFING and INSTALL DOORS activities would all be identified as activity 16-22.

Finally, as each activity is considered for its proper place in the network, the following questions should be asked:

1. What activities must be completed before this activity starts?

2. What activities can be accomplished concurrently?

3. What activities immediately follow this activity?[8]

II. Estimating Activity Times

In completing the network diagram the interrelationships of all the activities in the project have been determined and the duration of each activity can now be estimated.

Step No. 3 - Estimate Duration of Activities

This is best accomplished by making a separate listing of all the project activities and then assigning a duration to each activity on the list without regard to target dates, tentative schedules, or the project network. This system will eliminate the tendency of the estimator to assign activity durations based on some preconceived or tentative schedule. In order for CPM to realize its full potential the project durations should be estimated on the basis of the normal time for the activity according to the contractor's established capabilities and experience and irrespective of schedules and other activities.

The activity durations for this project have been estimated in days and tabulated as shown in Table No. 1. Referring to Figure 7 it can be seen that the durations listed in Table No. 1 have been posted under their respective activities.

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[8] Stilian and others, loc. cit.

TABLE 1.
ACTIVITY DURATIONS

i	j	Activity Description	Duration (Working Days)
2	4	SITEWORK	1
2	6	PREP SHOP DWGS	3
2	8	DEL STEEL	4
4	8	EARTHWORK	2
6	10	APPR SHOP DWGS	4
8	12	FLOOR SLAB	8
10	12	DEL DOORS	4
12	14	WALLS	12
14	16	ROOF	10
14	22	ELECTRICAL	3
16	18	MECHANICAL	1
16	20	INSTALL DOORS	1
16	22	ROOFING	2
18	22	DUMMY	0
20	22	DUMMY	0
22	24	PAINT	1
24	26	CLEAN UP	1

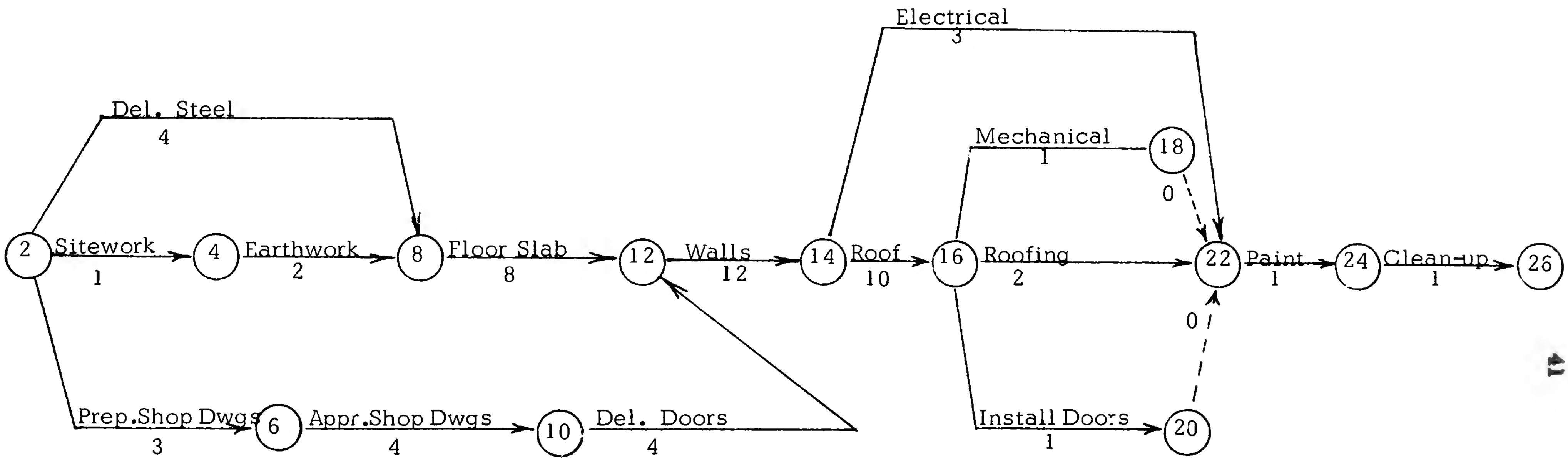

Figure 7. Network With Durations Posted

Comments on Step No. 3

In estimating activity durations special mention should be made of the activities which involve concrete. The important feature here is that time must be allowed for curing. In general this amounts to 7 days, but this creates a special problem because the curing takes place for 7 consecutive days and the estimates are in terms of working days; therefore, a value of 5 days was used for the curing process to allow for curing over the weekend. Calendar dates can be indicated on the critical path schedule if desired and the method of doing this will be explained shortly.

The use of the term normal time is especially significant and it merits further discussion. This is the time it would usually take the contractor to complete a given activity based on (i) his past experience with the same type of work, (ii) using the usual number of men in each craft, and (iii) working the normal eight hour day, five days a week without overtime.

III. Determining the Critical Path

From the previous definition of the Critical Path, it is apparent that the longest time path through the network must now be found. Unfortunately, the project network is small and the critical path is almost apparent with some minor mental manipulations. However, if the project is of say two or three hundred activities, it would soon become thoroughly frustrating to try to determine

it by eye and some systematic procedure must be used. The purpose of the next step is to demonstrate a manual procedure for determining the critical path for any project regardless of size.

Step No. 4 - Find EET and LET

Establishing the Earliest Event Time (EET) and the Latest Event Time (LET) for each event is the key to determining the critical path.

The method for accomplishing this is a simple arithmetic procedure in which the duration of all the time paths leading to each event are compared in order to find the earliest time that the particular event may be reached. Then the same process is used in reverse starting at the end of the project to find the latest time that each event will be reached.

To illustrate the calculation of EET the simple network problem of Figure 1 has been subjected to this process and the results are shown in Figure 8.

The EET's for Figure 8 were determined as follows:

a. The project begins with Event No. 1 and there are no arrows terminating at this event therefore the EET is O.

b. At Event No. 2 the only arrow leading into it has a duration of 5 days. Adding 5 days to the 0 days from Event No. 1 gives an EET of 5 days.

c. Activities B and C both terminate at Event

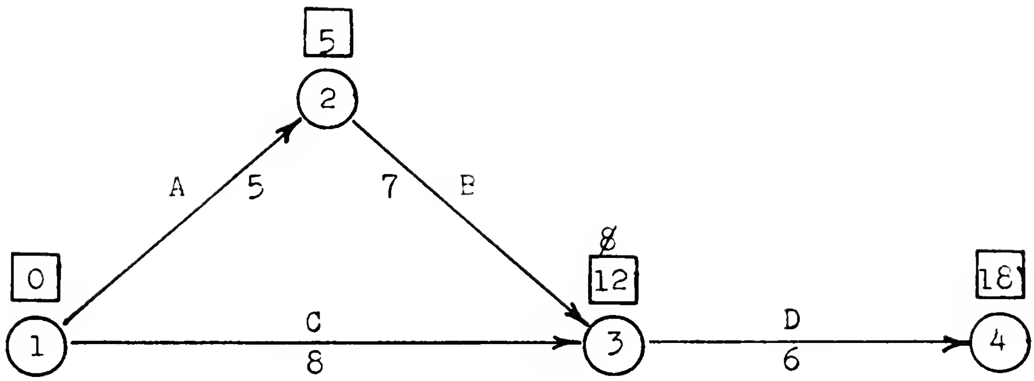

Figure 8. Calculation of EET

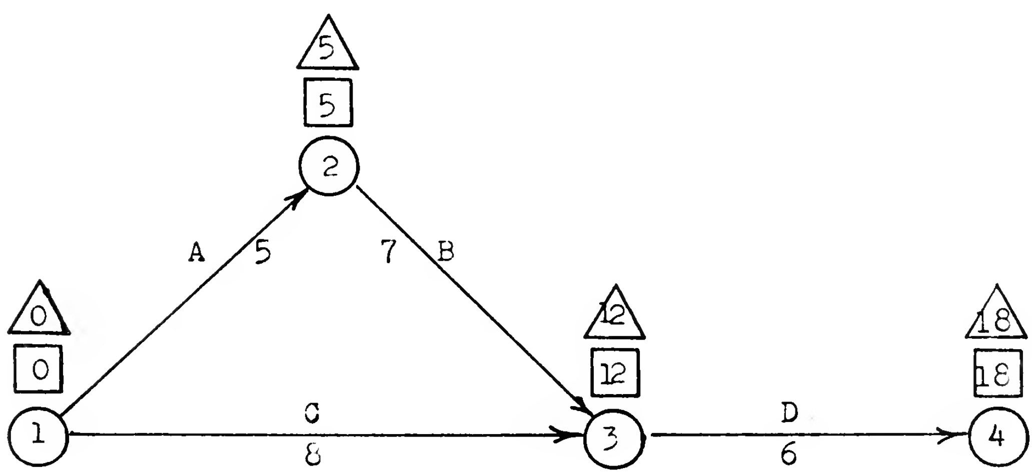

Figure 9. Calculation of LET

No. 3. Adding an EET of O from Event No. 1 to the duration of Activity C which is 8 days gives a tentative EET of 8 for Event No. 3. The 8 is then jotted down over Event No. 3. B is the only other activity terminating at Event No. 3 and its duration is 7 days. Adding 7 days to the EET of the preceding event (Event No. 2) which is 5 days gives a value of 12 days. Thus 12 becomes the EET for Event No. 3 which means that 12 days is the earliest possible time that Event No. 3 may be reached; i.e., Activity C will be completed in 8 days but Activity D cannot start until both B and C are completed and B won't be completed until the 12th day.

d. Only Activity D ends at Event No. 4 therefore the EET for Event No. 4 is 12 + 6 = 18 days. Since Event No. 4 is the last event in the project the EET indicates that the project from start to finish will require 18 days.

To find the LET's for all the events the above procedure must be reversed. This is demonstrated by Figure 9 and the explanation of this is as follows:

a. Beginning with Event No. 4 it can be seen that there are no activities that emanate from it therefore the LET is 18, the same as the EET.

b. Since Activity D is the only activity between Event No. 4 and Event No. 3, the LET of Event No. 3 is computed as follows:

LET Event No. 4	18
less duration Activity D	-6
LET Event No. 3	12

c. Working backwards from Event No. 3 there are two paths to consider, Activities B and C. First, the LET for Event No. 2 is determined:

LET Event No. 3	12
less duration Activity B	-7
LET Event No. 2	5

The LET for Event No. 2 is therefore 5 since there is only one path leading back to Event No. 2.

d. There are two paths by which Event No. 1 may be reached. First consider the path from Event No. 3:

LET Event No. 3	12
less duration of Activity C	-8
LET Event No. 1	4

The 4 could be jotted down over Event No. 1 but this is unnecessary because LET of O is obviously required at Event No. 1 since it is the beginning of the project. Finally consider the path from Event No. 2 to Event No. 1:

LET Event No. 2	5
less duration Activity A	- 5
LET Event No. 1	0

Activity A therefore makes the network balance. If neither activity A nor B provides an LET of O at Event No. 1 an error has been made in our calculations.

After this exercise, the calculation of the EET's and LET's for the Radiation Block House Project Network should be easily accomplished. It is suggested that a free hand sketch of Figure 7 be made and the EET's and the LET's calculated and recorded for each event on the diagram just as in the simple network problem. Having done this the results may be compared with Figure 10.

Comments on Step No. 4

This manual forward approach reverse approach procedure for computing the EET and the LET for each event of a project network can be used for any project regardless of size. It should be mentioned; however, that it becomes a rather time consuming chore for projects of more than 100 to 150 activities.

Step No. 5 - Identifying the Critical Path

Once the EET's and LET's have been determined the critical path may be readily identified. The criteria for identifying activities on the critical path are:

1. The EET and the LET at the point of the activity arrow are equal.

2. The EET and the LET at the tail of the same arrow are equal.

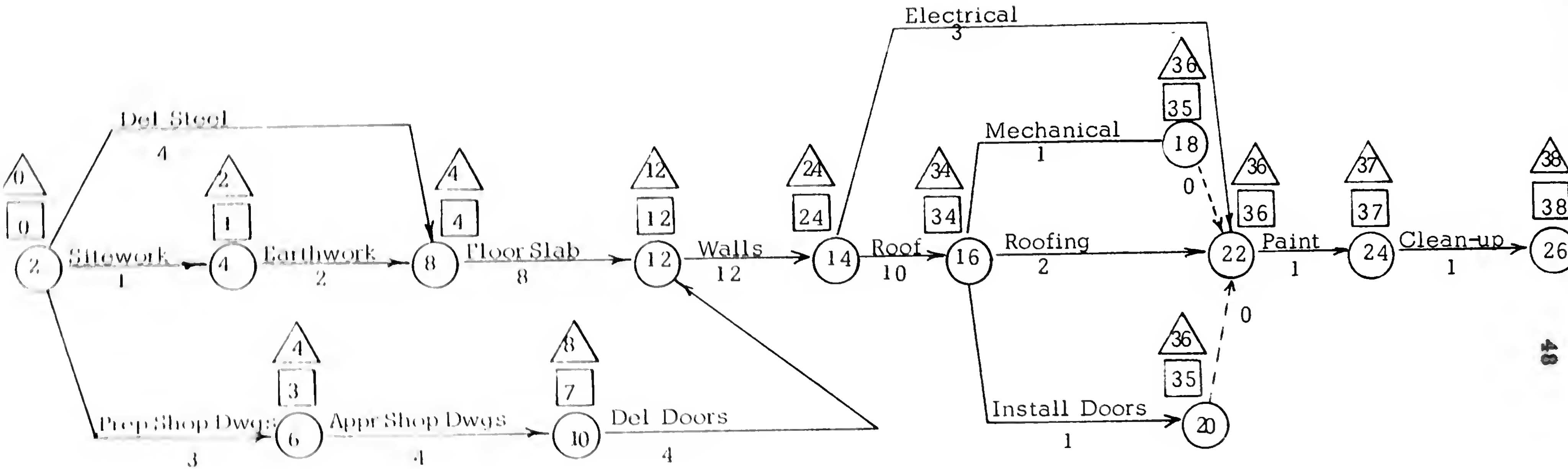

Figure 10. Completed Project Network

3. The difference between the equal EET and LET at the point of the activity arrow and the equal EET and LET at the tail of the activity arrow is the same as the duration of the activity.

All three criterion must be met for the activity to be a critical activity.

Refer to Figure 9 and find the activities that satisfy the criteria. This turns out to be activities A, B, and D therefore the critical path for this network, based on the arithmetic EET/LET procedure, is via events 1, 2, 3 and 4.

Now refer to Figure 10. and subject activity 16-22 (ROOFING) to the 3 criterion test.

1. At the head of the arrow EET = LET = 36 therefore criterion No. 1 is met.

2. At the tail of the arrow EET = LET = 34 and criterion No. 2 is satisfied.

3. (36 - 34) = 2 which is equal to the project duration of 2 days.

Thus all three criterion are met and this is a critical activity.

Continue this procedure until a chain of critical activities is established from the beginning to the end of the project. When this is accomplished the critical path is established and it may then be identified by hatching the critical activity arrows just

as in Figure 10.

Comments on Step No. 5

It is not uncommon to find a network with more than one critical path. Such is not the case for the Radiation Block House project but if it were the items on both critical paths would have to be treated with the same sense of urgency. It should be noted that compressing one of the critical activities by one day would cause the path containing the compressed activity to become non-critical since it would then have a float of 1 day.

IV Adjusting the Network

CPM's great appeal can be attributed to its use of the principle of management by exception; i.e., concentration of maximum effort on the activities that lie on the critical path. The aspect that many persons fail to grasp; however, is that it is the manipulation of the activities containing float that results in the greatest economy and the most efficient use of resources.

Project costs and resources will be discussed in this section immediately after a brief discussion of float.

Float

From the earlier definition of float (total float) it is known that all the paths in the project network other than the critical path must have a certain amount of float time. This can be computed for each activity by the following formula:

TOTAL FLOAT = (LET)j - (EET)i - Duration

Where (LET) j is the Latest Event Time at the head of the activity arrow and (EET) i is the Earliest Event Time at the tail of the same arrow. For example, consider activity 6-10 (APPR SHOP DWGS):

TOTAL FLOAT = 8 - 3 - 4 = 1

Activity 6-10 therefore has 1 day of float. It should be noted that activities 2-6 and 10-12 also have 1 day of float each which brings to light an important feature of the Total Float concept, namely:

> All of the activities of the same path have the same amount of total float and conversely a gain or loss of float by any activity on this path will affect all of the other activities.

To illustrate this rule assume that in the Radiation Block Project (Figure 10) activity DEL DOORS is delayed 2 days. This would make its duration 6 days instead of 4 days, and if the project network is reworked using 6 days instead of 4 days for the duration of DEL DOORS it would be found that not only do all the activities on path 2-6-10-12 lose the original 1 day of float but the entire project is delayed an additional day making the project completion time 39 days with path 2-6-10-12 becoming the critical path.

There is a method for computing total float without tallying the EET's and the LET's on the network diagram. It is simple and straight-forward but in order to use it the following

terms must first be defined:

TF-- Total Float

ES-- Earliest time that an activity may start. It is equal to EET

EF-- Earliest time that an activity may finish and it equals EET plus activity duration

LS-- Latest time that an activity can start. This is equal to the LET minus the activity duration

LF-- Latest time that an activity may finish. It is equal to the LET.

Table No. 2 presents all of the above values in tabular form for the Radiation Block House Project. It is felt that the following aspects of Table No. 2 deserve special mention.

1. Activity 14-22 (ELECTRICAL) has the greatest amount of float, i.e.; 9 days which means that after the WALLS are finished there is a period of 12 working days in which the 3 days of ELECTRICAL work may be performed.

2. Both dummy activities (18-22 and 20-22) contain 1 day of float as do the other items on the same path; therefore, they too comply with the previously stated rule for Total Float.

3. The best procedure for filling in the table values is to (i) start at the top of the ES and EF columns working down to the last activity, and (ii) work the LS and LF columns from the bottom

TABLE 2
COMPUTATION OF TOTAL FLOAT [a]

ACTIVITY		DURATION	ES	EF	LS	LF	TF
2	4	1	0	1	1	2	1
2	6	3	0	3	1	4	1
2	8	4	0	4	0	4	0
4	8	2	1	3	2	4	1
6	10	4	3	7	4	8	1
8	12	8	4	12	4	12	0
10	12	4	7	11	8	12	1
12	14	12	12	24	12	24	0
14	16	10	24	34	24	34	0
14	22	3	24	27	33	36	9
16	18	7	34	35	35	36	1
16	20	1	34	35	35	36	1
16	22	2	34	36	34	36	0
18	22	0	35	35	36	36	1
20	22	0	35	35	36	36	1
22	24	1	36	37	36	37	0
24	26	1	37	38	37	38	0

Note: TF=LF-ES-Duration

When TF = O The activity is critical

[a] Waldron, op. cit., p. 44.

back up to the first activity.

As mentioned earlier, the definitions of Free Float, Interfering Float, and Independent Float will not be undertaken other than to say that:

Free Float = (EF) - (ES of activity immediately ahead).

Interfering Float = Total Float - Free Float.

Independent Float = (EET)j - (LET) i - Duration.

In regard to Independent Float , Waldron states, "There is no known practical use for this number".[9]

There is however, one other type of float called Distributed Float that can be used to good advantage in construction work. This provides a means of overcoming the fact that total float is the same for every activity on a common path. It works by assigning a weighted value to each activity on the common path, then adding up the weights and proportioning the total float of the common path to each activity on the path. The weight assigned to each activity is based on the programmers experience and his evaluation of the work involved.

Manpower Allocation

Figure 11.0 is a network representing a hypothetical

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[9] Waldron, op. cit., p. 40.

project which is to be accomplished if possible without hiring extra men to supplement a presently available work force of 9 men and with out an extension of contract time. If the workload peaks could be leveled to a maximum of 9 men the job could be accomplished with our regular employees and this would result in a savings. CPM is ideally suited to handle this situation as will now be shown.

First, the number of men required on a daily basis for each activity under normal working conditions is tabulated:

TABLE 3
DAILY MANPOWER REQUIREMENTS

Activity	Duration	Manpower Required
1-2	3 days	3 men each day
2-4	4 "	5 " " "
1-4	5 "	2 " " "
1-3	6 "	4 " " "
3-4	4 "	3 " " "

Next, the CPM Network is manipulated so that it can be presented in bar chart form while maintaining the network relationships. This is illustrated by Figure 11.1

In Figure 11.1 it should be noticed that each day of the project is represented by a column and in each column is placed the

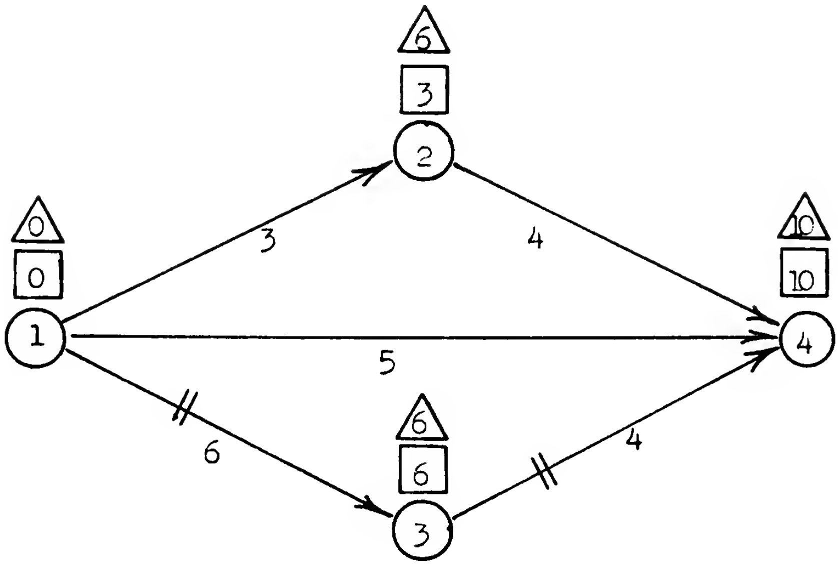
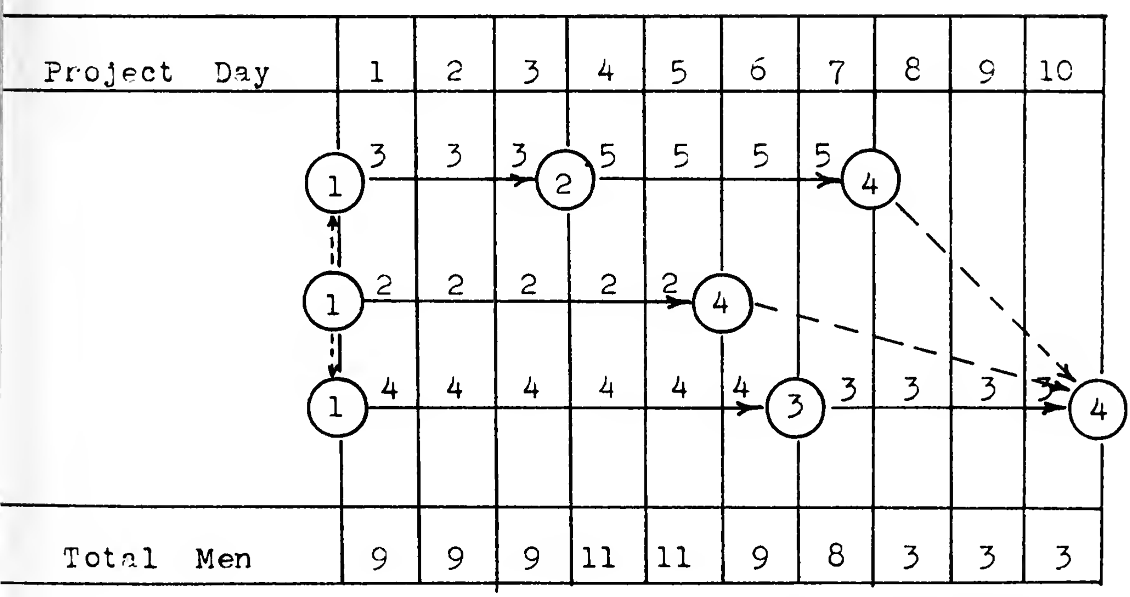


Figure 11.0 Manpower Network



Total man-days: 75

Figure 11.1 Manpower Chart

daily manpower requirements for each activity. By adding the daily manpower requirements for each activity. By adding the daily manpower requirements for all the activities that are concurrent the total number of men required daily is obtained.

As previously stated, the normal working force available is 9 men on any one day. This would require two additional men on the 4th and 5th days unless this peak can be eliminated.

Figure 11.1 indicates that all of the activities were started at the earliest possible time. What happens now if the start of Activity 1-2 is delayed for 3 days and these men sent to work on another project? This activity's 3 days of float is used up but from figure 11.2 it can be seen that by this adjustment we have accomplished the following:

a. The manpower is held down to the normally available working force.

b. The project is still completed on schedule.

c. The same total number of man days are involved.

This procedure may be expanded to handle larger projects and several computer programs are available to take the drudgery out of this operation.

Calendar Dating

It is often more meaningful, especially as far

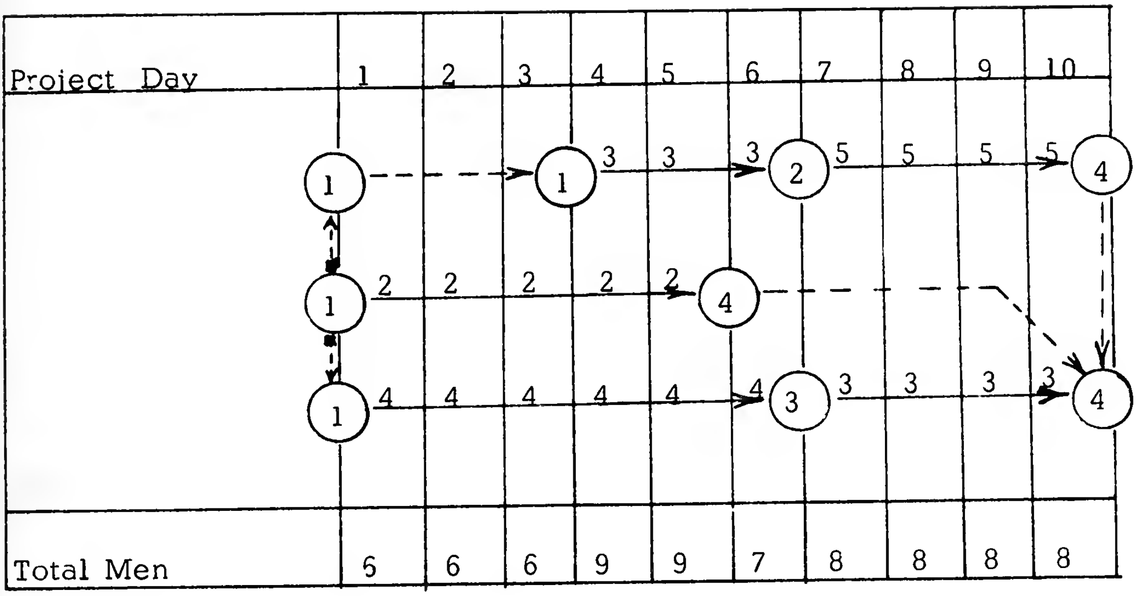
as owners and sub-contractors are concerned, to indicate the completion dates of various project activities. The network which indicates working days can be readily converted to calendar dates by simply constructing a tabulation of the project days and then listing next to them the appropriate dates allowing for week-ends and holidays.

As an example, assume that a project is 15 days in duration and it begins on 16 March 1964. The listing is made as follows: [10]

TABLE 4
CALENDAR DATE CONVERSION

Project Day	Calendar Day	Project Day	Calendar Day
1	3/16/64	9	3/26/64
2	3/17/64	10	3/27/64
3	3/18/64	11	3/30/64
4	3/19/64	12	3/31/64
5	3/20/64	13	4/1/64
6	3/23/64	14	4/2/64
7	3/24/64	15	4/3/64
8	3/25/64		

[10] Waldron, op. cit., p. 45.



Total man-days: 75

Figure 11.2 Revised Manpower Chart

These dates can then be indicated on the network by either labeling the activities in question or drawing a calendar scale beneath the network and adjusting the lengths of the activity arrows so that their projection on the scale below indicates the proper date.

Determination of Optimum Project Costs

A frequent issue in many construction projects is the cost of expediting the job. In this area CPM provides the contractor with a method of analyzing his project in order to get the most out of his construction dollar.

There are many reasons for wanting to expedite a construction project. Some of these are:

a. To take advantage of a bonus for early completion.

b. To recover time lost due to inclement weather.

c. To meet the owners needs for early occupancy.

d. To finish the work as fast and as economically as possible in order to increase the firm's volume of construction work.

Frequently when a job appears to be falling behind schedule, Project Managers will put everyone on overtime. To someone familiar with CPM this is clearly a wasteful practice since the extra effort should be applied first to the critical activities. Even to an experienced contractor without knowledge of CPM this is obviously not the proper approach but he is not always certain which activities to expedite and in what sequence they can be

expedited most economically.

CPM offers an excellent method for investigating the economics of expediting construction work. Generally, there are two cost boundaries or extremes within which a contractor must work. In CPM one is called the Normal Cost and the other the Crash Cost. They are defined as follows:

Normal Cost: The total project cost if all the activities are accomplished in their normal times with their usual size work crews and no overtime work.

Crash Cost: The total project cost if all activities are compressed to their minimum times by means of additional work shifts, larger work crews, and overtime.[11]

When time is of the essence and it is necessary to reduce the normal project time the optimum means of accomplishing this lies somewhere between these two cost boundaries. This relationship is shown in Figure 12.[12]

It should be noted that the curve connects all the minimum costs for the given project durations which illustrates an

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[11] GE - 225 Application, op. cit., p. 16.

[12] GE - 225 Application, op. cit., p. 14.

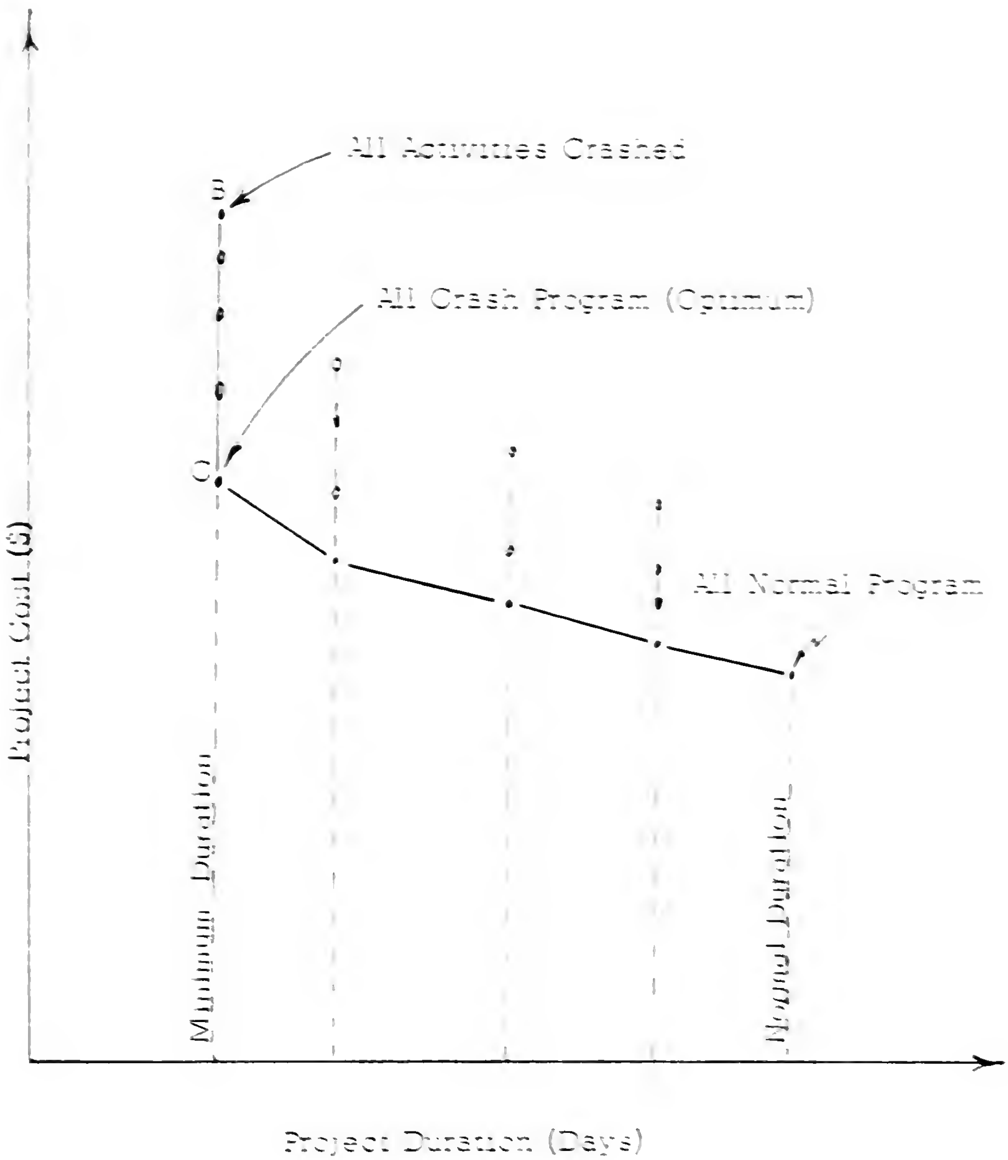

Figure 12. Normal vs Crash Costs

important point that is not readily apparent.

As activity times are compressed the critical path changes and more than one critical path may and usually does develop. Since different activities will cost different amounts to expedite them the most economical solution is the one that involves the activities that cost the least to expedite. In other words, by being selective about the activities that are compressed the least costly method of accelerating the project can be found.

The parameter used to select the activities with the least cost is called the cost slope and it is computed for each activity as shown below:

$$\text{cost slope (\$/day)} = \frac{\text{crash cost-normal cost}}{\text{normal time-crash time}}$$ [13]

To illustrate how this works consider Figures 13.0 and 13.1 which are further extensions of the manpower network shown in Figure 11. Figure 13.0 represents the original estimate for a project proceeding on a normal basis while Figure 13.1 shows the same project with all activities "crashed" (compressed as much as possible).

In Figure 13.1 the critical path has changed to path 1-2-4 and the project time has been reduced to 5 days. To analyze

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[13] GE - 225 Application, op. cit., p. 15.

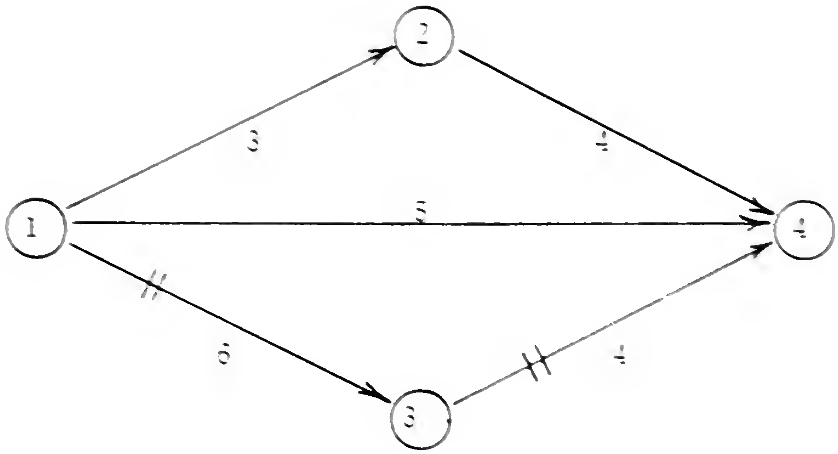

Figure 13.0 Normal Program

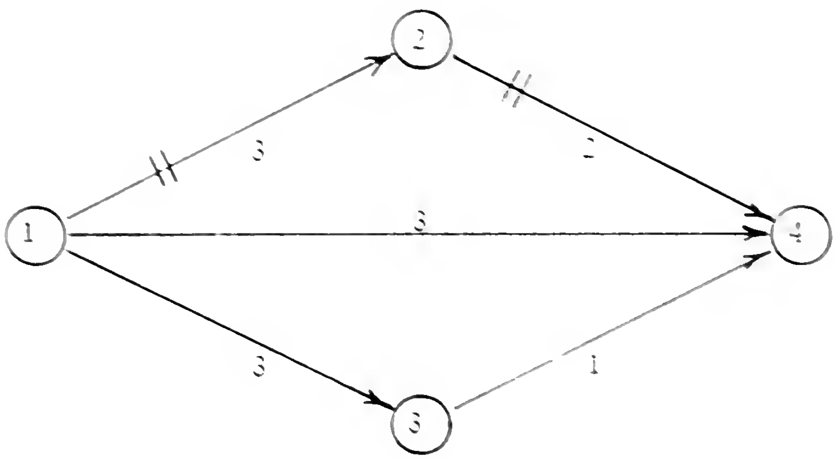

Figure 13.1 Crash Program

what this means in terms of cost, some cost estimates have been assumed placed in tabular form (Table 5) and the cost slope has been computed for each activity.

TABLE 5
COMPUTATION OF COST SLOPE

Activity	All Normal Time	All Normal Cost	All Crash Time	All Crash Cost	Cost Slope
1-2	3	$450	3	$450	*
1-3	6	900	3	1200	$100/da
1-4	5	750	3	1000	125/da
2-4	4	300	2	400	50/da
3-4	4	400	1	850	150/da
Total Cost		$2800		$3900	

Sample Slope Calculation:

$$\text{cost slope (1-3)} = \frac{\$1200 - \$900}{6 - 3} = \$100/\text{day}$$

* for purposes of illustration we have assumed that this activity cannot be expedited.

It should be noted that the total All Normal cost of $2800 corresponds to point A in Figure 12 and the All Crash cost of $3900 is at point B.

Now that the cost slopes for all the activities of this

project have been developed the information necessary to select the most economical means of expediting the project is available, at least as far as direct costs are concerned. Indirect costs will be considered later.

It is assumed that the project time is to be reduced to the maximum extent possible within economic reason. In reducing the project time the first approach is naturally via the critical path activities. In this case there are two choices: activities 1-3 or 3-4. Comparing the cost slopes of these two activities it can be seen that the best choice would be to reduce activity 1-3 first because it has the least cost per day, i.e., \$100/day versus \$150/day.

The maximum amount that activity 1-3 may be reduced is 3 days which brings it to the lower limit (the crash point). It is then necessary to turn to activity 3-4 for further time reductions.

Activity 3-4 may likewise be reduced by 3 days to its crash point of one day if still further reductions are needed but this creates another problem. When path 1-3-4 was initially reduced by 3 days to 7 days another critical path appeared--path 1-2-4 which is also 7 days in length. This means that for all further reductions both critical paths must be considered, and finally when both of these paths are reduced to 5 days, path 1-4 becomes a critical path and it must also be considered for reduction of less than 5 days.

It is obvious that the most the project duration may

compressed is to 5 days since the activities on path 1-2-4 are at their crash limits. The question to be asked now is: Does Figure 13.1 represent the optimum schedule for least cost, since all projects have been compressed as much as possible?

Five days is the best that can be done time-wise but not cost-wise because the two remaining paths have some unnecessary float that was gained through compressing their activities to the maximum extent possible. Therefore activity 1-4 may be relaxed from 3 days to its normal schedule of 5 days and path 1-3-4 may be relaxed by 1 day to 5 days at a considerable savings and without affecting the new 5 day schedule.

A problem of choice now remains. Since path 1-3-4 may be relaxed only 1 day which activity should be increased? The answer is activity 3-4 since it is the more expensive of the two to compress. Now the optimum 5 day project schedule has been obtained and it should lie cost-wise somewhere between the 10 day Normal schedule of $2800 and the 5 day All Crash schedule of $3900. The breakdown for the optimum 5 day schedule is as shown in Table 6.

It can be seen then that by accelerating the activities on the basis of least slope in combination with the relaxation of other activities which contain float the optimum 5 day Crash schedule is achieved and a savings of $400 ($3900 - $3500 = $400) is realized.

This schedule corresponds to point C in Figure 12.

TABLE 6
COST OF OPTIMUM 5 DAY SCHEDULE

Activity	Normal-Time	Cost	Slope	5 Day-Time	Cost
1-2	3	$450	-	3	$450
1-3	6	900	$100	3	1200
1-4	5	750	125	5	750
2-4	4	300	50	2	400
3-4	4	400	150	2	700
				Total	$3500

5 Day Cost = Normal Cost + (Days Reduced X Slope)

Now that the project has been compressed to its minimum time while maintaining a sense of economic equilibrium the optimum schedule which lies somewhere between the optimum All Normal Cost point and the optimum All Crash Cost point should be investigated. This presupposes, of course, that it is no longer necessary to compress the project time to its limit, but rather an ideal schedule may now be sought in terms of both time and cost.

This ideal or optimum schedule must be based on Total Project Cost and in order to find this schedule one other important cost item must be considered --the Indirect Cost. In the broadest

sense, this cost consists of home office overhead, project overhead, and depreciation.

The Indirect Cost curve is easily generated because it is merely a function of the daily overhead costs for the entire project and therefore it increases in proportion to the project duration. The Total Project Cost than is the sum of the Direct Cost and the Indirect Cost and this relationship is demonstrated in Figure 14.[14] A point on the Total Project Cost Curve in Figure 14 is produced by adding the direct cost and the indirect cost from their respective curves for a given project duration. The optimum project time and cost are then defined by the coordinates of the lowest point on the Total Cost Curve.

To demonstrate the determination of the optimum project schedule the Manpower Network of Figure 11 will be used.

Thus far the following 2 points on the optimum Direct Cost Curve have been established:

All Normal Cost	10 days at $2800
Optimum Crash Cost	5 days at $3500

The additional points necessary to complete the optimum Direct Cost Curve may be determined by assuming project durations that lie between 5 and 10 days and by using the method of compressing

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[14] Monahan, J.O., "The Critical Path Method - How to Use It", Construction Methods and Equipment, (May 1962), p. 135.

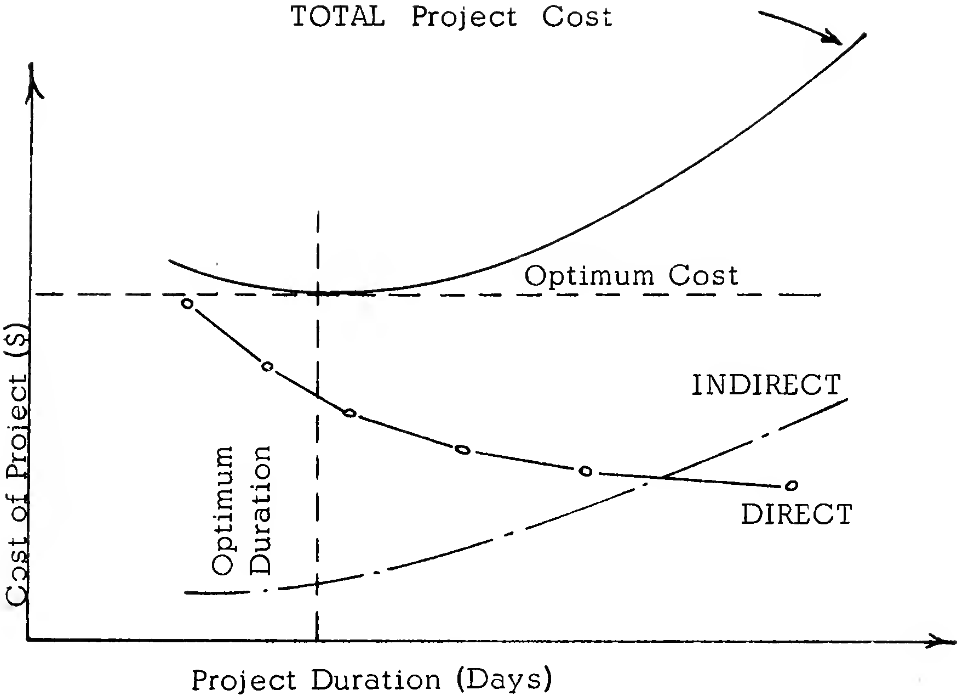


Figure 14. TOTAL Cost Curve

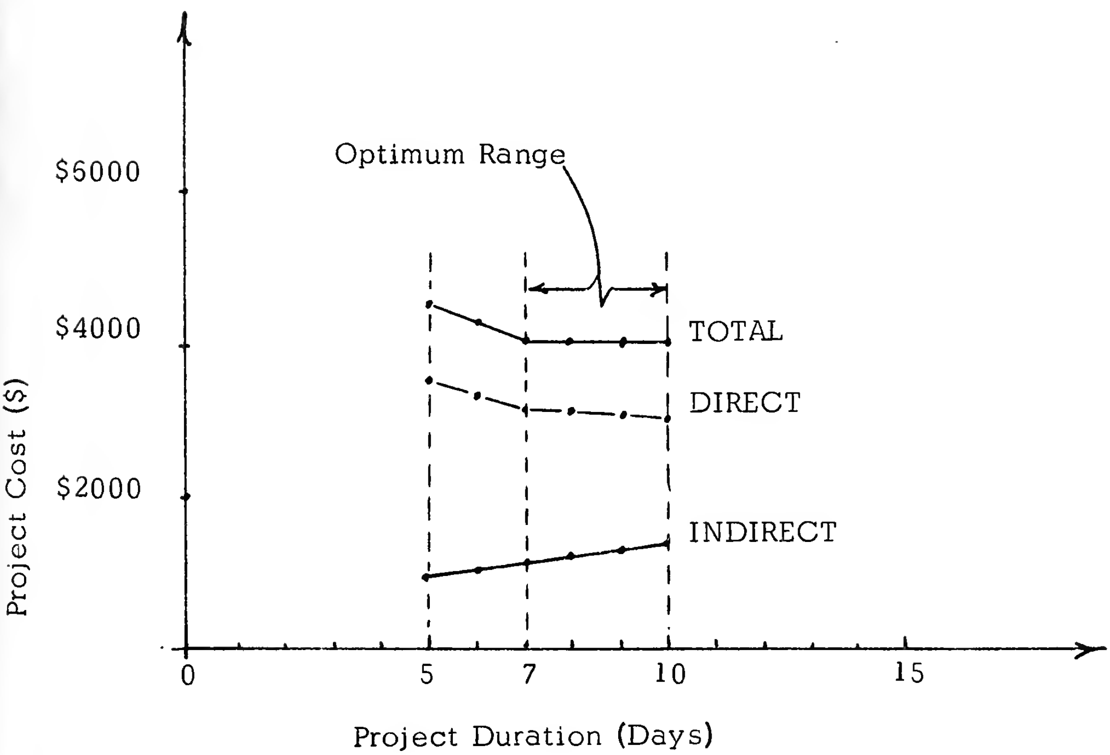


Figure 15. TOTAL Cost Curve

activities on the basis of least cost slope and relaxing the non-critical activities. This will provide the corresponding optimum costs.

For the Indirect Cost Curve for this project assume that it has been determined that the Indirect Costs amount to $100 per day starting at a minimum cost for 5 days of $800. This curve can be easily plotted and when added to the optimum Direct Cost Curve from which the optimum project schedule can be obtained as shown in Figure 15.

Another convenient way to determine the Total Cost is by developing the following tabulation: [15]

TABLE 7
CALCULATION OF TOTAL PROJECT COSTS

Project Duration	Direct Cost	Indirect Cost	Total Cost
10 days	$2800	$1300	$4100
9 "	2900	1200	4100
8 "	3000	1100	4100
7 "	3100	1000	4100
6 "	3300	900	4200
5 "	3500	800	4300

[15] White, G.L., "Computerized Project Network Analysis," <u>The Military Engineer</u>, (July-August 1963), p. 238.

From both Table 3 and Figure 15 it is apparent that the optimum schedule is 7 days at a cost of \$4100. Actually there is a range of 7-10 days where the cost is the same but the best philosophy on this is to complete the work as soon as possible and put the effort into finishing up the firm's other projects.

It is, of course, not necessary to use both the cost tabulation and the cost curves to determine the optimum schedule. Either will suffice. The advantage in using the curves is speed since a good approximation of the Direct Cost Curve can be obtained by connecting the All Normal point to the Optimum Crash point by a straight line thus eliminating the calculation of the intermediate points.

One other noteworthy piece of information may be gleaned from this exercise. Suppose the owner were offering a bonus of \$100 per day for each day that the project is completed ahead of schedule. If the original duration is 10 days it can be seen that the job can be completed in 7 days for the same cost and a \$300 bonus obtained in the process.

Along with this discussion of project completion times and bonuses it would also be worthwhile to explore the subject of CPM and liquidated damages.

Suppose that the project illustrated by the well-worn Manpower Network has been contracted for completion in 5 days

and the contract stipulates that liquidated damages will be assessed at the rate of $50 per day for each day that the project is delayed beyond the contract completion time of 5 days. With a normal completion time of 10 days, the project is obviously in trouble.

Question: Should the project be allowed to slip a few days and the contractor pay the damages or is it better to put a maximum effort into it and finish up in 5 days?

Referring to Table 3 there is obviously no point in letting the contract drag out beyond 7 days therefore it would be prudent to investigate only 3 possibilities: completion on the 5th, the 6th and the 7th day.

5th Day:

Project Cost	$4300
Contract Price	- 4100
Extra	$ 200
Liq. Damages	0
Total Additional Cost	$ 200

6th Day:

Project Cost	$4200
Contract Price	- 4100
Extra	100
Liq. Damages	50
Total Additional Cost	$ 150

7th Day:

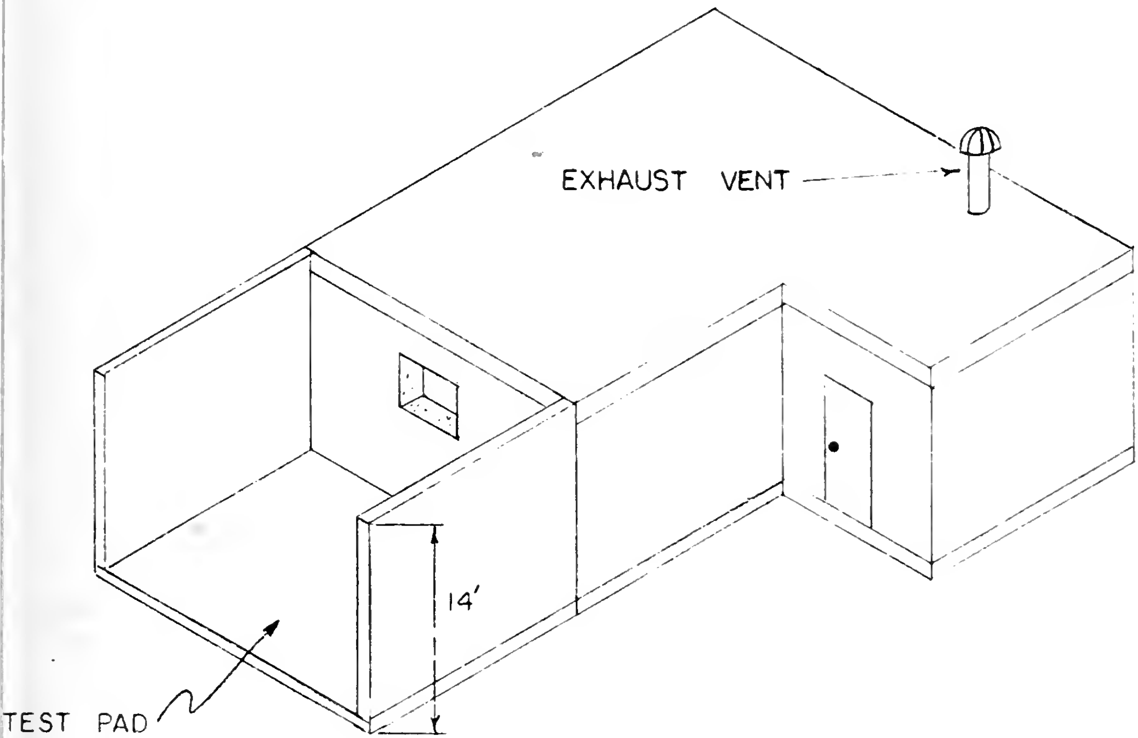
Project Cost	$4100
Contract Price	-4100
Extra	0
Liq. Damages	100
Total Additional Cost	$ 100

It can be concluded then that it is actually less expensive to let the contract slip 2 days and pay the penalty than to attempt to finish on time. If the contract runs beyond 7 days the Total Additional Cost will increase at the rate of $50 per day; i.e., $150 for 8th day, etc.

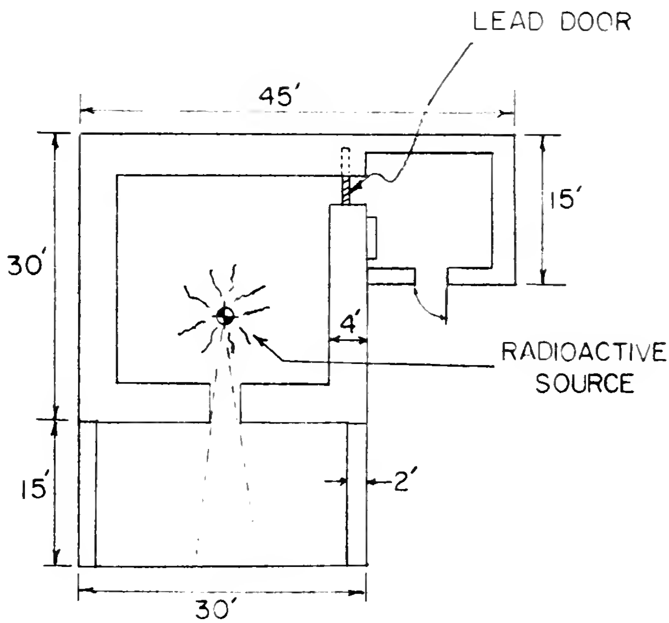
Finally, after 10 days our Direct Costs will begin to increase due to our own inefficiency and the Total Project Cost will soon get out of hand.

Summary

It is this writer's opinion that CPM's greatest potential is in the area of cost control. At the present time most firms are satisfied to work with only CPM scheduling; however, there is a noticeable trend toward a greater emphasis on cost. The ultimate result of this trend will undoubtedly be the development of new construction cost accounting procedures which will be based on the use of Electronic Data Processing Systems.



—— ORTHOGRAPHIC VIEW ——



—— PLAN VIEW ——

RADIATION BLOCK HOUSE

PLATE NO. I

ADMINISTRATION OF CPM

Use of Computers

At the present time the most controversial aspect of CPM is: which is better, computer solutions or manual solutions?

The leading proponent of the manual method is Professor John Fondahl of Stanford University. His argument against the use of computers if founded on the fact that certain basic assumptions must be made; therefore, computer solutions are only as good as the assumptions are valid. He further feels that by using a computer a certain amount of judgement control is relinquished since the computer can only make "canned" decisions--not logical ones.

A leading champion for the opposition to this viewpoint, Mr. Herbert Berman of Mauchly Associates, Inc., believes that the calculation of minimum cost expedited schedules and investigations for the optimum use of manpower and material resources involve such vast amounts of information of information that hand calculations become virtually impossible.

Taking the approach that a computer is a high speed electronic calculator that can and will only perform in accordance with specific instructions and is not an electronic monster that may eventually take over the human race, there seems to be no reason why a computer should not be used in CPM to eliminate the tedious calculations required in large projects.

Even Professor Fondahl admits: "To date, the application of CPM is still in the development stage." "A non-computer approach appears justified as a stepping stone between the conventional methods and the sophisticated computer systems." [16] This is tantamount to saying that if the system is to be most effective, computer solutions must be employed.

The issue then is really a question of how large a project must be before the use of a computer becomes practical.

The general consensus of opinion is that it should be somewhere in the neighborhood of 100 to 200 activities. A specific figure cannot be given because a firm's capacity for manual calculations depends to a great extent on the capability of its personnel and its administrative procedures. Some firms have found it profitable to subject all their projects, regardless of size, to CPM and in doing so they have reorganized to include a CPM Division. The Mardian Construction Co. of Phoenix, Arizona, for example, has a full-time Civil Engineer in charge of CPM. [17]

There are many CPM computer programs available and a list of the typical CPM and PERT programs is included in the Appendix.

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[16] Fondahl, J., "Can Contractors Own Personnel Apply CPM Without Computers? Part II.", The Constructor, Dec. 1961.

[17] "Arizona Contractor Applies Computer CPM to All Jobs - Large and Small, for Time and Cost Control", Reprint from The Constructor by Reuben E. Donnelley Corp. (New York, not dated), p. 34.

One of the most impressive programs is the General Electric (PROMOCOM) system which utilizes the GE-225 computer. It is apparent that a great deal of thought and effort has gone into the development of this program in order to achieve its simplicity while generating a great deal of useful information. To illustrate the beauty of this program the only information required of the contractor is:

a. An identification of all the project Activities.

b. Normal and Crash durations of each Activity.

c. Normal and Crash costs of each Activity.

d. A Network Diagram.

From this input data the following information can be obtained:

1. For each activity the computer will provide: description, duration, cost, scheduled completion date, float on the basis of weighting factors, earliest possible start, earliest possible completion, latest allowable start, latest allowable completion and the activity status (critical or non-critical).

2. All Normal and All Crashed solutions providing costs and durations.

3. One or more expedited schedules, as requested, giving costs and durations.

4. Revised schedules based on network changes.

5. Calendar dating if given the project start date, holidays, and length of work week.

General Electric has established Information Processing Centers (IPC's) at 6 locations in the United States equipped with GE-225 computers in order to provide a Data Processing Service to contractors. The locations of these centers is included in the Appendix with a list of other firms specializing in CPM.

With GE's IPC arrangement the contractor may obtain the services of a CPM consultant or mail the necessary input information listed earlier to an IPC and GE will provide the desired output data by return mail.

There are also a number of Computer Service Bureaus in the major cities of the United States that are able to provide a similar service but they utilize different programs.

There is nothing mysterious about using computers with CPM. All that is required is to provide the input information in a form that can be assimilated by the computer. Generally, this is the same as for a manual solution and the particular firm offering the data processing service usually has a data input form that is easily filled out. The GE-225 CPM Program Input Form is shown in Plate No. II.

In fact, it is so easy to have a computer perform all the tedious calculations that there is a danger that people may lose

sight of the why's and wherefore's and become mesmerized number punchers.

On the other hand, a person who insists that CPM is not dependent on computers will never realize the full potential of CPM. Construction work by its very nature contains an infinite number of variables thereby lending itself naturally to the solution of its problems by data processing systems.

The best way to get started in CPM is by learning and applying the manual approach. This also provides a good opportunity to appreciate and understand the value of computers in CPM. After several manual applications of CPM a person is usually ready, willing and eager to have a computer handle the calculations.

It seems inevitable that in the future CPM will be a standard tool for all construction contractors. Then, perhaps, will be seen the beginning of another phase of development in project administration--complete cost accounting and scheduling by electronic data processing systems.

Administrative Costs

There is no denying that the use of CPM will add to a project's overhead costs. This is true regardless of the use of computers--a fact that many people fail to realize.

Very often the only costs that are mentioned for CPM are in terms of computer time. The costs usually overlooked are:

a. Time spent by personnel in developing the network.

b. Time expended by these same personnel updating the network and administering the project with the Critical Path Schedule.

c. Cost of drafting and reproducing CPM networks.

d. CPM consultants fees.

e. Cost of instructing personnel in use of CPM.

Even though the cost of computer time is by far the largest expense, the items mentioned above should not be neglected.

Information on overall costs is sparse but the following statement, although qualified, is of value:

> A small company doing \$5 to \$10 million gross per year could plan its jobs by CPM --if planning is all it requires--for \$30,000 a year, provided that it rents time on a computer in a data processing center. [18]

Actually the supplementary costs as well as the computer costs will vary from office to office and from area to area, therefore it is more important to be aware of what costs are involved

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[18] Tiner, W.D., "The Many Faces of CPM", Building Construction, (February 1964), p. 47.

rather than how much it costs a particular firm to administer CPM.

Since each firm can easily establish its "in house" administrative costs the remainder of this section will be devoted to a discussion of the cost of computer time, consultants, and instruction. The final item will be the preparation of a bid estimate which will serve to put the cost information presented in this section into its proper perspective.

Computer Costs

Figures commonly quoted for computer time range from $100 to $150 per hour. This, of course, is not especially informative since most people have no idea how much computer time will be needed to run their program.

Some firms are more realistic; however, and offer computer services based on the number of activity arrows in the network. For example, the following prices were quoted by the General Electric Company:

Initial Run:

$0.25 per activity for the first 200 activities

$0.20 " " " " next 300 "

$0.15 " " " " balance of "

Up-Dating (Monitor) Run:

$0.15 per activity for the first 500 activities

$0.10 " " " " balance of "

plus 6 cents for each new input card punched

These prices are valid for a single schedule calendar dated output. If a more sophisticated or dynamic treatment of the program is desired such as one that would provide several expedited schedules you can expect to pay approximately $.50 per activity for the first 500 activities.

One feature that should be pointed out regarding the method of computing charges is that as the project progresses activities will be completed and hence they will be deleted from future up-dating runs so that the cost will be progressively less for each monitor run. This is also true of by-the-hour rates since less time is required to run the program but this value is somewhat less tangible.

A Washington, D.C. contractor engaged in the construction of a $1 million apartment building has reported that a CPM network of 535 activities has cost him $194 for an initial run and one monitor run including assistance of a CPM specialist and punchcard preparation. [19]

Consultants Fees and Instruction

Consultants may be obtained from the firms listed in the appendix for fees that generally range from $125 to $200 per day plus travel expenses.

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[19] White, G.L., "An Introduction to Computerized CPM", Reprint from The Constructor, by Reuben H. Donnelley Corp., (New York, not dated), p. 30.

They can be hired for consultation regarding a specific project or to instruct the firm's personnel in the applications of CPM.

Three to five day CPM seminars are also offered by several firms. For example; the General Electric Computer Department in Dallas, Texas offers a 3 day Critical Path Method Workshop which consists of instruction in the fundamentals of manual and computer oriented programs at a cost of $100. A. James Waldron offers a wide range of instructional programs from a one day executive seminar for top management personnel at $300 plus travel expenses to a 5 day training course at $1000 plus $100 per attendee, plus travel expenses.

Sample Bid Estimate

Project Description: Construction of Radio Relay Stations at 3 sites. The work in general at each site consists of a reinforced concrete building, tower foundation, and site work. Approximate total cost $300,000. Contract time is 20 weeks for Sites #1 and #2 and 24 weeks for Site #3. Owner requires initial CPM schedule 2 weeks after award of contract and an up-dated schedule every two weeks thereafter until completion of job for each site. In addition, as a basis for payment, the contractor is required to submit an up-dated CPM schedule on the first day of each month listing completed activities. Owner also states that network should consist of 400-700 activities. Assume 600 activities at beginning of project for each site.

Cost Breakdown:

CPM Consultant:	
$15.00 per hour, 8 hours per day	
for 2 days	$240
Travel, food, lodging	160
	$400
CPM Instruction:	
Project Manager to Dallas for	
3 day seminar	$100
Travel, food, lodging	200
	$300
Site No. 1 (20 weeks):	
Initial Run	
200 act. at 25 cents	$ 50
300 act. at 20 cents	60
100 act. at 15 cents	15
	$125
Monitor Runs	
500 act. at 15 cents	$ 75
100 act. at 10 cents	10
300 act. at 6 cents	18
Cost of 1st run	$103

For 10 runs aver. cost $= \frac{\$103}{2} \times 10 =$	\$515
Drafting, Printing, Misc.-allow	200
	\$840
Site No. 2 (20 weeks):	
Same as site no. 1	\$840
Site No. 3 (24 weeks):	
Initial Run	
Same as site no. 1	\$125
Monitor Runs	
12 at $\frac{\$103}{2}$	\$618
Drafting, Printing, Misc.-allow	\$225
	\$968

Summary:

Consultant	\$400
Instruction	300
Site No. 1	840
Site No. 2	840
Site No. 3	968
	\$3348
Overhead and profit at 10%	335
Total Estimate	\$3683

Comments on the Estimate

The cost of applying CPM to this project is just

over 1% of the value of the contract which is certainly not a negligible expense. Considering the size and duration of the project, the number of monitor runs seems excessive and a substantial savings could be realized by eliminating some of these. This is of course up to the owner.

A savings could also be achieved if the size of the original network can be reduced from 600 activities to the specified lower limit of 400 activities. This should not be difficult for a project of this size.

The inclusion of the one-time expenses for the CPM consultant and for CPM Instruction is a matter of personal judgement. These could have been absorbed in the general overhead and profit item but in this case they have been included at full cost with the thought that they will off-set the possibility that the projects might run beyond 20 or 24 weeks and require additional monitor runs.

The CPM consultant will be hired to set up the original project network and the Project Manager will be sent to Dallas for 3 days to learn CPM so that he will be able to up-date and administer the CPM networks after they have been developed by the consultant.

The cost of the monitor runs for each project is based on the average cost for the number of runs required. This is necessary because with each successive monitor run the number of activities diminishes thus reducing the cost from $103 for the initial monitor

run to a final run cost of say $10. It is also assumed that for any particular run half of the total number of activity cards will have to be re-punched at 6 cents each.

Recommended Practices

Getting Started With CPM

If a firm's needs are immediate the safest and surest way to get started is by hiring a consultant. In this case an attempt should be made to obtain a CPM specialist with construction experience since many of these personnel are mathematicians or management specialists whose knowledge of construction is limited. This is not a mandatory requirement but it is conducive to the communication of ideas.

Firms that haven't yet bid a contract in which the use of CPM is required may be assured that it will not be long before they are faced with this situation. It is therefore recommended that they begin now to develop a CPM capability within the firm.

As a first step it is recommended that they select someone in the firm to become the "CPM Expert" and send him off to school as soon as possible. This person should preferably be a Civil Engineer with a good background in construction methods and contract administration. This is not to say that only a graduate civil engineer can learn CPM, but that they have the natural

qualifications for becoming CPM specialists. In order to develop a CPM network a person must have knowledge of the sequence in which construction operations are normally conducted. Once a firm has developed a "CPM Expert" he can train the rest of the staff.

Ideally a CPM Team should be established consisting of the Project Manager, the estimator, and the job superintendant. In addition this team should be augmented with representatives of appropriate sub-contractors. The purpose of this team is to develop the project network. Once this is accomplished each member of the team should receive a copy of the completed network and each sub-contractor should be prepared to complete his work as scheduled.

In order for CPM to be effective it <u>must</u> receive 100% support from everyone concerned. If it is treated as an interesting diversion and not taken very seriously it will become an expensive nuisance and eventually fall flat.

<u>Using CPM to Best Advantage</u>

If CPM is to be used to its maximum effectiveness the final phase of application should consist of using it to control the project. In this way its dynamic potential will be realized. This means that the network should be reviewed and up-dated at frequent intervals. Most firms do this once a week by requiring the job superintendant to submit a corrected network every Friday afternoon.

The amount of information that management in the home office can glean from a CPM network is almost frightening. The result, of course, is that the people in the office for a change have an accurate picture of what is going on in the field and can thus better support the field effort.

It should be mentioned that it is not necessary to wait for a new job to start before CPM can be applied. There have been many cases of partially completed contracts which were seriously behind schedule that were pulled out of the fire by CPM. All that is necessary in this case is to neglect the completed activities and draw the network based on the activities remaining to be completed. The duration of activities already in progress would be only the time estimated to complete these activities.

An excellent use of CPM is to justify time extensions for changed conditions and additional work. Many contractors have found that CPM is extremely valuable when negotiating with owners and architects.

CPM also offers a solution to the old problem of trying to get partial payments from owners in less than 30 to 60 days after they are requested. For instance, a system could be devised so that payment periods could be indicated on the CPM schedule. The percentage of the work completed would be a function of the completed activities up to a particular pay period and

this could be computed in advance. It would therefore only be necessary for the architect or engineer to indicate that the activities prior to the pay period in question were completed and the check could then be immediately issued by the owner.

A situation that the contractor should be wary of is a contract that includes a CPM schedule developed by the owner or the architect. It must be recognized that it is practically impossible for this schedule to accomodate all of the different contractors that might be bidding a job since every contractor has his own construction methods and procedures. In this case, the schedule whould be examined carefully and exceptions taken to it where necessary. Ideally, the CPM schedule should be developed by the contractor.

Finally, after the project is completed a copy of each CPM network should be retained with the contract file. This will provide an excellent record of the progress of the job should the need for this information ever arise.

GENERAL ELECTRIC · GE 225/CPM AND PROJECT MONITOR AND CONTROL METHOD CODE SHEET

Computer Department
Phoenix, Arizona

I	J	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Slope Optional	W	C/N	Normal Time Estimates a OPTIMISTIC	m MOST LIKELY	b PESSIMISTIC	Project Code ALPHA, OR NUMERIC	NUMERIC ONLY	Activity Description	T/C	Wk • Day / Day month	YR
1 2 3	4 5 6	7 8 9	10 11 12	13 14 15 16 17	18 19 20 21 22	23 24 25 26	27	28	29 30 31	32 33 34	35 36 37	38 39 40	41 42 43 44	45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72	73	74 75 76 77 78	79 80

LEGEND

I - The event number at the tail of the activity arrow.
J - The event number at the head of the activity arrow.
W - A digit from 1 to 9 - The weight of this activity in relation to other activities (for purposes of float assignment).
C.N - A continuous or non-continuous cost curve (specify).
T.C - Transaction code: A Add, B Begin, C Change, D Delete, E End.

NOTE: All Changes on this code sheet that will require changes in the arrow diagram should be explained on the reverse side of the form.

DATE - Can be expressed in either fiscal or calendar form
Examples: - May 23, 1962 in fiscal system is represented by 21.4 62
March 24, 1963 in calendar system is represented by 24MAR63
Only one dating system can be used in a project.

Network Identification

Prepared by

Date

CK-69 (Rev 10 '62)

COURTESY OF GENERAL ELECTRIC

PLATE NO. II

APPENDIX

Network Analysis Techniques

Firms Offering CPM Services

Computer Programs

Answers to Network Problems

NETWORK ANALYSIS TECHNIQUES

Acronym	Definition	Remarks
CPM	Critical Path Method	Used mainly by the construction industry; also referred to as CPA (Critical Path Analysis) and CPS (Critical Path Scheduling)
PERT	Program Evaluation and Review Technique	The most effective technique for research and development projects. Used by U.S. Navy in development of Polaris Missile.
COT	Control Operation Technique	A computer oriented technique similar to CPM but does not use a network diagram.
PEP	Program Evaluation Procedure	Obsolete U.S. Air Force designation for PERT.
LESS	Least Cost Estimating and Scheduling	A computer oriented technique similar to PERT developed by IBM. Especially

		good for manpower leveling.
CPSS	Critical Path Planning and Scheduling	Term used by Army Corps of Engineers for CPM.
RPSM	Resources Planning and Scheduling Method	Developed by Mauchly Associates as an extension of CPM which takes manpower and other resources into account.
PROMOCOM	Project Monitor and Control Method	CPM Computer Program developed by the General Electric Company.
TRACE	Task Reporting and Current Evaluation	Basically a PERT/COST type system emphasizing cost of labor and materials.
RAMPS	Resources Allocation and Multiproject Scheduling	Produces a schedule for each resource.

PARTIAL LIST OF FIRMS OFFERING CPM SERVICES

AS OF APRIL 1964

1. Adams Associates, Inc.

   Anaheim, California and Bedford, Massachusette

2. Management Systems Corporation

   Newport Beach, California

3. Operations Research, Inc.

   Silver Springs, Maryland and Santa Monica, California

4. A. James Waldron

   Haddonfield, New Jersey

5. Mauchly Associates, Inc.

   Fort Washington, Pennsylvania

6. Management Services Corporation

   Raleigh, North Carolina

7. The General Electric Company

   Information Processing Centers

Bethesda, Maryland	Dallas, Texas
New York, New York	Phoenix, Arizona
Schnectady, New York	Chicago, Illinois

Services may also be obtained through the area or local offices of the following firms:

IBM

Remington-Rand

RCA

SOME TYPICAL AVAILABLE COMPUTER PROGRAMS [a]

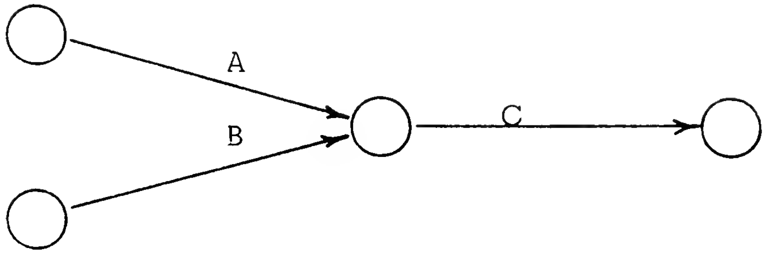
Computer	Equipment	Technique	Capacity	Event Numbering	Remarks
IBM-1620 (IBM) Miss-Less	20K 40K 60K	CPM	Max. Ev. No. + No. Act. 1614 3614 5614	Random Max. 1999	Includes cost summary 23 col. description
IBM-1620 (IBM)	20K, 40K up	PERT	695 Act. 999 Act.	Random	Updating routine Multiple begin & end events Req's. auto-divide for probability 31 col. description
IBM-1620 (IBM) less	20 to 60K	CPM	Max. Ev. No. + No. Act. 1672	Random Max. 999	Includes cost summary 23 col. description
IBM-1620 (IBM) Less	20K	CPM	2500 events		
IBM-7070	10K w/1401-4K	PERT		sequential	
IBM-704	10 tapes	CPM & Cost expediting	592 Activ. or 527 events	Ascending Max. J 32768	2 cards for description 29 col. description selection of schedules Activity slope or not selector
IBM-1401 (IBM)	4K	CPM	527 events	Sequential Consecutive	25 col. description
IBM-1401 IBM)	8K-(Mult. 12K-(Div. - 16K-(Compare)	CPM	985 events 1555 events 2125 events	Sequential Consecutive	25 col. description

IBM-7070/ 7074 (By IBM) Taxis	10K 7501 crd. Rdr. 8 tapes	PERT	2000 Activities or 1000 Events	Random 10 charac-ters	25 col. descrip-tion Has updating rou-tine 5 output sorts, 1 terminal event Probability
IBM-650 (IBM) Less		CPM	500 events	I < J	Start with No. 1
IBM-650 (IBM) Less		CPM & Resource Allocation	500 events	I < J	Resource leveling 10 resources, 10/activity
IBM-1620 (IBM)		CPM	999 events	I < J	Cost summation Single terminal event
NCR-304 & 315 w/cram (National Cash)		Activity Oriented PERT	4000 Act.	Random	Updating routines 30 col. description
Philco-2000 (Philco)		PERT	750 Act.	Random	Named "WCC PERT" 7 output sorts
Rem-Rand S.S. 80 (ORI)		PERT II	Unlimited	Random	Scheduled dates Output sort options
Rem-Rand S.S. 80/90		CPM	2800 events	I < J	Cost summation
RCA - 501		PERT & Resource Forcasting	2000 Act. or 1000 events		9 resources, 9/act. Output in graph form Gives Hi, Low & Ave. points for rates of expendi-ture
GE-225	8K words 4 tapes	CPM & Cost Expediting	1000 events or 2100 Activ.	Random Max. 999	By assigning arbi-trary weight factor to activity will distribute float 52 col. descrip-tion

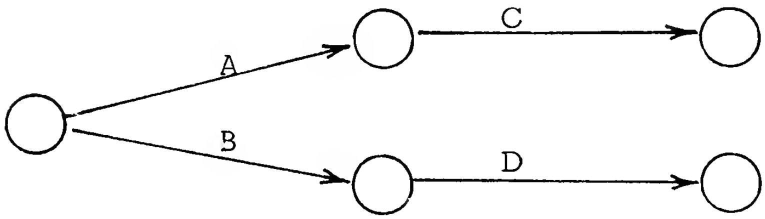
[a]Courtesy of A.J. Waldron

Answers to Network Logic Problems

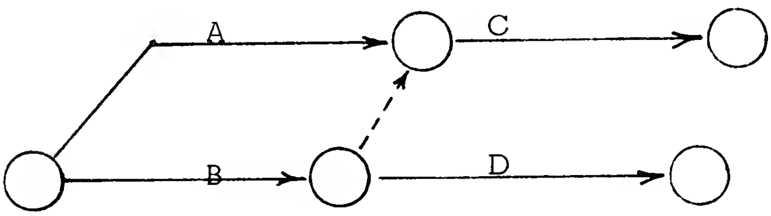
1.



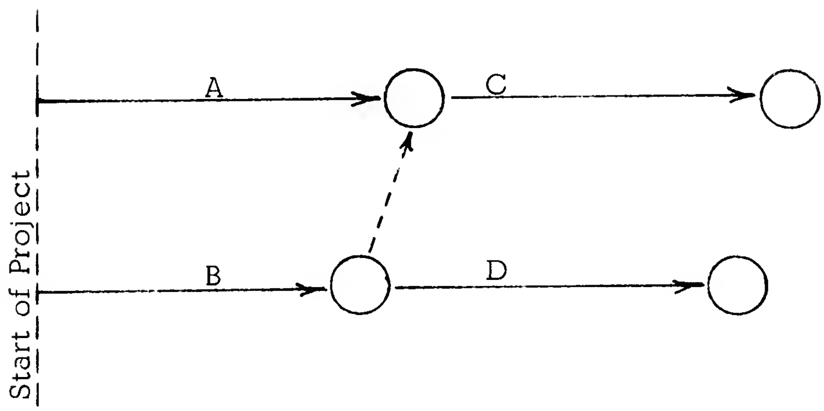
2.



3.

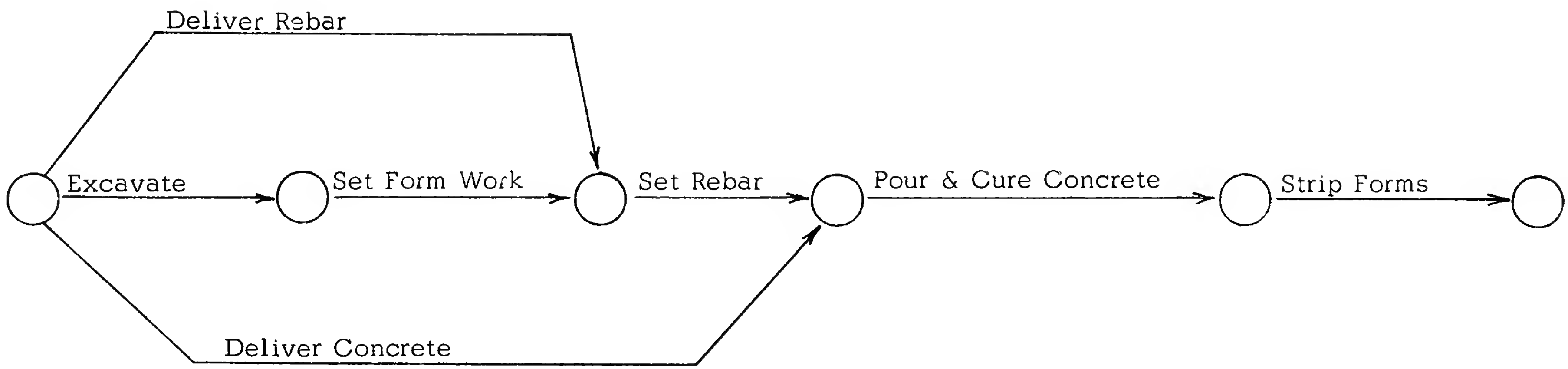


Alternate Solution:



Network Logic Problems (Continued)

4.



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BIOGRAPHY

Frederick Mueller Derr was born on July 10, 1932 in Plainfield, New Jersey. He began his elementary school education in Plainfield; however, in 1941 he moved to Fort Lauderdale, Florida with his parents and in 1950 was graduated from Fort Lauderdale High School.

He enlisted in the U.S. Navy in 1952 and, in 1953 won an appointment to the U.S. Naval Academy, Annapolis, Maryland. He graduated with the class of 1957 and was commissioned an Ensign in the Civil Engineer Corps, U.S. Navy.

After a brief tour of duty at the Naval Training Center, Bainbridge, Maryland he entered Rensselaer Polytechnic Institute, Troy, New York under a Navy Sponsored program and received his Bachelor of Civil Engineering Degree in August 1959.

His next assignment was in Southeast Asia where as Assistant Officer in Charge of Construction he was responsible for the administration of contracts for design and construction of roads, airfields and military facilities in Thailand, Laos and South Vietnam. While in Southeast Asia he was promoted to his present rank of Lieutenant.

In November 1961 he returned to the United States and was assigned to the Naval Propellant Plant, Indian Head, Maryland. As the Assistant Resident Officer in Charge of Construction he was responsible for the administration of construction contracts for in-

dustrial facilities in support of the Polaris and other missile programs.

In 1963 he was selected for the Navy Postgraduate Education Program in Civil Engineering and was sent to Tulane University at his request to earn the Master of Science Degree.

He obtained his New York State Engineer-In-Training certificate in 1959 and is now a Registered Professional Engineer in Civil Engineering in the State of Louisiana.

Mr. Derr's interest in the Critical Path Method was first aroused as a result of his desire to find a system that could be used to expedite certain high priority construction contracts at the Naval Propellant Plant.